EXHIBIT A

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Task Modeling and Specification for Modular Sensory Based Human–Machine Cooperative Systems

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***Abstract*—This paper is directed towards developing Human-Machine Cooperative Systems (HCMS) for augmented surgical manipulation tasks. These tasks are commonly repetitive, sequential, and consist of simple steps. The transitions between these steps can be driven either by the surgeon's input or sensory information. Consequently, complex tasks can be effectively modeled using a set of basic primitives, where each primitive defines some basic type of motion (e.g. translational motion along a line, rotation about an axis, etc.). These steps can be "open-loop" (simply complying to user's demands) or "closed-loop, in which case external sensing is used to define a nominal reference trajectory.**

The particular research problem considered here is the development of a system that supports simple design of complex surgical procedures from a set of basic control primitives. The three system levels considered are: i) task graph generation which allows the user to easily design or model a task, ii) task graph execution which executes the task graph, and iii) at the lowest level, the specification of primitives which allows the user to easily specify new types of primitive motions. The system has been developed and validated using the JHU Steady Hand Robot as an experimental platform.

I. Introduction

Human-Machine Cooperative Systems combine human decision-making with sensory-robotic enhancement to accomplish complex tasks. The tasks performed in such a manner are typically difficult or impossible to perform without the human being physically present in the loop. There are two main communities where HMCS systems have been used extensively: i) telerobotics and ii) medical interventions. In the first case, HMCS have mainly been used in remote [1] and hazardous environments [2]. Microsurgery, which is also the key application considered in this paper, is one example of the latter, [4].

In terms of surgical applications, HMCS provide assistance and augmentation to surgeons during surgical procedures. Typically, the surgeon directly manipulates a tool which is also attached to a robot. Consequently, the behavior of the robot can be controlled either by i) complying to the user input, or ii) using the available sensory feedback to enhance the performance of the user. There are two operating scales commonly considered during procedures governing the type of feedback used. For cases of micro-scale manipulation (eye-surgery), visual feedback is commonly used. On the macro-scale, both force and visual feedback are facilitated. This implies that different levels of assistance/augmentation are needed depending on the current stage of the surgical procedure.

In the development of our system, the following issues were considered:

i) The system has to be *modular* - complex tasks should be defined using a set of basic control primitives. This allows the surgeon to model a variety of tasks using the existing architecture.

ii) The system should be able to provide the *appropriate* assistance to the user based on the task at hand. This is solved by allowing the surgeon to define different types of *constraints* depending on the operating scale.

iii) The system should be *flexible* to allow the users to easily change the existing model for the task they want to perform.

iv) The system should be *scalable* so that that the system structure executes both simple and complex tasks with same efficiency.

v) And finally, the system should have a *theoretical foundation* that allows for synthesis and verification.

The paper is organized as follows. In Section II a short overview of the related work is given. In Section III, the basic design of the system is presented. The notion of basic primitives required to design complex tasks is given in Section IV. Task specification approach is outlined Section V. The principles of task graph generation are presented in Section VI followed by the task execution strategy in Section VII. This is followed by an example in Section VIII.Finally, Section IX provides short summary and outlines avenues for future research.

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II. Background and Related Work

In general, robots have no skills and require detailed instructions to complete high-level plans. Skills represent higher-level programming primitives which are task-relevant. In terms of HMCS, these primitives can be sensor and/or user guided. In other words, sensors should provide measurements for task-driven control. Closed-loop visual servoing can be used to achieve more stringent initial positioning preconditions compared to force based primitives. For medical applications, the system usually has some form of a model of the task being performed (or, at the far end, should be even able to build one). This is due to the fact that surgical procedures are repetitive and sequential. Therefore, similar to the Task Control architecture (TCA) [3], we can use a centralized process control model with a single supervisory module.

The work pursed in this paper builds upon the research presented in [5] and [6] . The former studies augmented surgical manipulation tasks in order to create an environment that makes it possible to easily and safely specify a set of control primitives (basic control modules) necessary for a number of different surgical procedures. The latter is concerned with the issue of providing the appropriate assistance to the users by recognizing their actions using continuous Hidden Markov Models.

Based on these, we are interested in building a system that provides an optimized augmentation based on the context of the task. Compared to the approach presented in [6], we propose an approach to task level modeling considering both unconstrained and constrained robot motion. By using a predefined modeling schema and a number of basic steps, it is easy for the user to model a variety of complex tasks. By using the proposed framework, the ideas in [5] can now easily be integrated in the system to build graphs for new tasks.

III. System Design

For each primitive, there are different requirements on the robot's behavior. By different behaviors of the robot, we consider translational and/or rotational motion, motion of a specific joint, etc. For each behavior, there may be safety constraints such as upper bound on the velocity, predefined level of stiffness/compliance based on the precision level, etc. An important issue in surgical applications is error recovery. In the current system, each state is therefore "glued" to an error state that can handle different types of error (discussed in more detail in Section IV).

As an example, retinal vein cannulation [7] involves *positioning* and *orienting* of a needle to the vicinity of the vein, *inserting* it when appropriate until contact is made. On contact, *puncturing* is performed, after which the needle can be safely *withdrawn*. These parts can be represented as *states* in a task graph, with *transitions* as connections between them, see Figure 1.

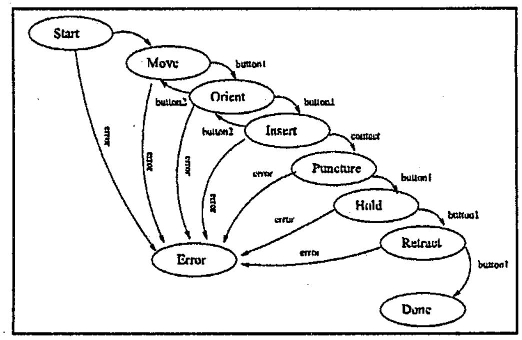

Fig. 1. An example of a basic task graph for vein cannulation.

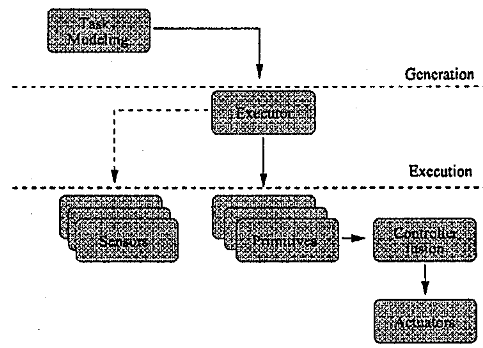

Fig. 2. The system architecture.

The current system is composed of three levels, see Figure 2:

i) Task graph modeling and generation allows the user to design and generate a graph for the task he/she wants to perform.

ii) Task graph execution - given the task graph, the system automatically initiates all the basic processes required to execute the task.

iii) A set of basic primitives is implemented and used during the execution of the first two levels. These primitives are the ones commonly used in surgical procedures. At this level, it is also easy to implement new primitives which are automatically detected by the previous two levels.

The system is currently tested using the JHU Steady-Hand robot [14], see Figure 3. The Steady-Hand is a 7DOF manipulator with XYZ translation at the base for coarse positioning, two rotational degrees of freedom at the shoulder, instrument insertion and rotation stages. There is a force sensing handle at the end-effector used to sense users' forces. Tools are mounted at the endpoint and

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Fig. 3. The experimental setup of the JHU Steady Hand Robot.

"manipulated" by the operator holding the force handle. The robot responds to the applied force allowing the direct control for the operator. The overall positioning accuracy of the robot is less than 10 micrometers.

IV. Basic Primitives

The instructions to the low-level motion controller of the robot are passed from the basic primitives. The primitives have a common interface with functions such as Start(), Run() and Stop(). The core functions are defined in a base class, so if the user wants to design a new module, all the basic functionality is inherited from the base class and only the module specific parts have to be implemented. Basically, these are the steps required:

- Assign a name to the class.
- Initialize the necessary variables in the Start().
- Implement the control loop in Run().
- Clean up in Stop().

A. Virtual Fixtures as a Control Law

In our implementation, "virtual fixtures" provide cooperative control of the robot manipulator by "stiffening" a hand-held guidance mechanism against certain directions of motion or forbidden regions of the workspace. It has been indicated by studies on virtual fixtures for teleoperation that user performance can increase as much as 70% with the fixture based guidance [15]. In our framework, virtual fixtures are used to implement basic control blocks for the system used on JHU SHR.

In what follows, we model the robot as a purely kinematic Cartesian device with tool tip position $\mathbf{x} \in SE(3)$ and a control input that is endpoint velocity $\mathbf{v} = \dot{\mathbf{x}} \in \mathcal{R}^6$, all expressed in the robot base frame. The robot is guided by applying forces and torques $\mathbf{f} \in \mathcal{R}^6$ on the manipulator handle, likewise expressed in robot base coordinates.

The guidance for JHU SHR is defined geometrically by identifying a space of "preferred" directions of motion. Let us assume that we are given a $6 \times n$ time-varying matrix $D = D(t)$, $0 < n < 6$, representing the instantaneous preferred directions of motion. Here, if n is 1, the preferred direction is along a curve in SE(3); if n is 2 the preferred directions span a surface, and so forth.

As an example, in Figure 1 the *Move* primitive would allow only the Cartesian base motion to move the remote center of motion (RCM) to the vicinity of the object to be manipulated. This is opposed to the *Orient* which uses only rotational and end-effector joints which keeps the RCM fixed for fine manipulation motions. The *Insert* primitive would allow only the motion along the current tool axis.

We define two projection operators, the span and the kernel of the column space, as

$$\mathrm{Span}(D) \equiv \quad [D] = D(D'D)^{+}D' \tag{1}$$

$$\mathrm{Ker}(D) \equiv \quad \langle D \rangle = I - [D] \tag{2}$$

where $^{+}$ denotes pseudo-inverse for the case where D is (column) rank deficient.

By decomposing the input force vector, $\mathbf{f}$, into two components

$$\mathbf{f}_D \equiv \quad [D]\mathbf{f} \tag{3}$$

$$\mathbf{f}_\tau \equiv \quad \mathbf{f} - \mathbf{f}_D = \langle D \rangle \mathbf{f} \tag{4}$$

and introducing a new admittance ratio $k_\tau \in [0, 1]$ that attenuates the non-preferred component of the force input, we arrive at an admittance control of the form

$$\mathbf{v} = \quad k(\mathbf{f}_D + k_\tau \mathbf{f}_\tau) \tag{5}$$

$$= \quad k([D] + k_\tau \langle D \rangle)\mathbf{f} \tag{6}$$

Thus, the final control law is in the general form of an admittance control with a time-varying gain matrix determined by $D(t)$. By choosing k, we control the overall admittance of the system. Choosing k_τ low imposes the additional constraint that the robot is stiffer in the non-preferred directions of motion. As noted above, we refer to the case of $k_\tau = 0$ as a *hard virtual fixture*, since it is not possible to move in any direction other than the preferred direction. All other cases will be referred to as *soft virtual fixtures*. In the case $k_\tau = 1$, we have an isotropic admittance.

As it will be shown in Section VI, during the task graph generation, the user can specify what type of motion is desired for the current primitive. Since all the primitives are added to the system dynamically at the beginning of the task execution, the system does not have to be compiled each time a new primitive is added.

B. Vision Based Virtual Fixtures as a Control Law

Some of the basic primitives incorporate additional visual feedback in the control loop. This way, the motion of the robot can additionally be constrained to a *reference*

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direction fixture, [12]. In terms of visually guided control [8], a number of basic primitives which enforce kinematic constraints can be defined. To obtain visual measurements, the XVision system, [13] is used.

What we have presented in the previous section directly supports motion in a subspace, but it does not allow us to define a fixed desired motion trajectory. If $\mathbf{u} = f(\mathbf{x}, S)$ is the signed distance of the tool tip from a surface S, we can define a new preferred direction as

$$D_c(\mathbf{x}) = [(1-k_d)[\mathbf{D}]\mathbf{f}/\|\mathbf{f}\| + k_d\langle\mathbf{D}\rangle\mathbf{u}] \quad (7)$$

$$\text{with } 0 < k_d < 1, \quad (8)$$

combining the two vectors that encode motion in the preferred direction and correcting the tool tip back to S. The constant k_d governs how quickly the tool is moved toward the reference surface. One minor issue here is that the division by $\|\mathbf{f}\|$ is undefined when no user force is present. As projection is invariant to scale, we write (7)

$$D_c(\mathbf{x}) = (1-k_d)[\mathbf{D}]\mathbf{f} + k_d\|\mathbf{f}\|\langle\mathbf{D}\rangle\mathbf{u} \quad (9)$$

$$\text{with } 0 < k_d < 1 \quad (10)$$

and apply (5) with $D = D_c$.

One potential problem with this control law is that when the user applies no force, there is no virtual fixture because there is no defined preferred direction. Thus, there is a discontinuity at the origin. However, in practice the resolution of any force sensing device is usually well below the numerical resolution of the underlying computational hardware computing the pseudo-inverse, so the user will never experience this discontinuity.

As an example, for a line following primitive which may represent a vessel, a *preferred motion* will be along the direction of the line. During the task execution, which may be to perform a cut along the vessel, whenever the user deviates form the line, an error vector is defined based on the distance to the line, [12].To bring the surgeon back to the line, the preferred direction can now be defined perpendicular to the line until the error is equal to zero.

C. Error Handling

For surgical applications, it is of inevitable importance for the system to handle different types of errors. The error can be reported either by the system or by the user by pressing a button on a keyboard. When in the error state, the surgeon can i) terminate the execution of the task, ii) return back to the state from which the error was reported, or iii) choose some other state and continue the task.

V. Task Specification

Our system provides the user with a plethora of basic primitives which can be easily combined to perform complex tasks. Another important feature of the system is also the ability to impose some basic requirements on the design of a task. For this reason, we have chosen to use the *XML Schema Definition Language (XSD)*, [11] based representation for a general class of procedures as follows:

```
<xs:element name="procedures">
    <xs:complexType><xs:sequence>
        <xs:element ref="event" minOccurs="1"
                 maxOccurs="unbounded"/>
       <xs:element ref="basisVector" minOccurs="0"
                         maxOccurs="6"/>
        <xs:element ref="procedure" minOccurs="1"
                 maxOccurs="unbounded"/>
-------------------------------------------------------
 <xs:element name="procedure">
    <xs:complexType> <xs:sequence>
        <xs:element name="description" type="xs:string"
    minOccurs="0" maxOccurs="1"/>
        <xs:element ref="state" minOccurs="1"
    maxOccurs="unbounded"/>
      <xs:attribute name="name" type="xs:string"
    use="required"/>
-------------------------------------------------------
<xs:element name="state">
    <xs:complexType><xs:sequence>
        <xs:element name="description"  type="xs:string"
            minOccurs="0" maxOccurs="1"/>
        <xs:element ref="transition"
            minOccurs="1"
            maxOccurs="unbounded"/>
        <xs:element ref="constraint"
            minOccurs="0"
            maxOccurs="unbounded"/>
      <xs:attribute name="name"
                    type="xs:string"
    use="required"/>
-------------------------------------------------------
<xs:element name="event">
    <xs:complexType><xs:sequence>
        <xs:element name="description" type="xs:string"
            minOccurs="0" maxOccurs="1"/>
      <xs:attribute name="type"  type="xs:ID"
    use="required"/>
-------------------------------------------------------
  <xs:element name="constraint">
    <xs:complexType> <xs:sequence>
        <xs:element name="description" type="xs:string"
       minOccurs="0" maxOccurs="1"/>
      <xs:attribute name="constr" type="xs:IDREF"
      use="required"/>
      <xs:attribute name="weight" type="xs:double"
      use="required"/>
```

In our system, we assume that surgical interventions can be modeled by a set of events, basis vectors and a procedure with a sequence of states. Events represent links or triggers between the states and are either sensory based (e.g. *contact detected*) or induced by the user (e.g. *button pressed*). Basis vectors span the task space of the robot. Using different types of operators on the basis vectors, we can easily define subspaces for preferred robot motion. States are represented by a set of transitions and constraints. Transitions are pairs (event, newState), i.e. for each event there is a newState defined.

There may be a number of constraints defined for a certain state. Those are directly connected with the behavior of the system through the control algorithm. As examples of constraints, there may be a value which defines the level

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of compliance/stiffness of the robot, definition of virtual fixtures, etc. According to this specification schema, the Extensible Markup Language (XML), [11] can now be used for task graph generation.

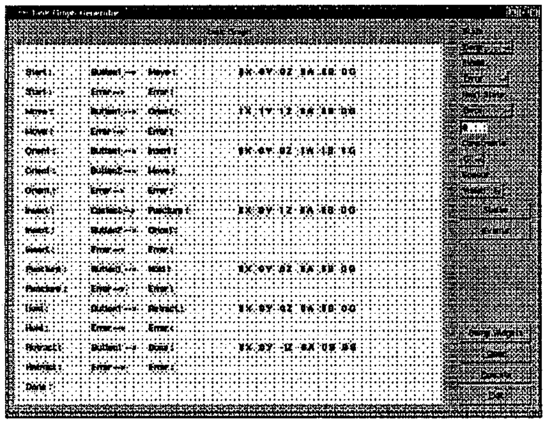

Fig. 4. Graph generation using a simple GUI. For each state, a number of events are specified. In addition, the user can define a set of preferred directions and their magnitude (X, Y, Z represent the three translational degrees of freedom and A, B and G represent the three axis of rotation). In addition, for each primitive the type of sensor can be defined.

VI. Task Graph Generation

There are three ways of generating a task graph:
i) **GUI** - using a graphical interface that relies on the system structure and the specification file, see Figure 4.
ii) **Learning** - in [5], it was shown how a simple language for modeling of multiple human–machine cooperative tasks can be designed. The underlying assumption was that a task is composed of *gestemes* - small component actions which are supported by the system. These are then be combined to generate task graphs on–line by recognizing users' actions.
iii) Directly specifying the XML file.

VII. Task Graph Execution

The task graph manager, see Figure 2, configures the *procedure* with its underlying structure to solve the task given the task graph. When invoking the control system, the task graph manager is initiated with command line parameters specifying a text file produced during task graph generation. The text file is interpreted so that the tree structure is built. After the task manager has received a confirmation that the whole tree is successfully configured, the system can be run. The system is event based and the task manager either decides which method to run or stops the execution in case of an error.

VIII. Example Scenario

Let us now study the execution of the vein cannulation procedure as shown in Figure 1. The following primitives are used to model the task:
MOVE: move the instrument from a starting position to some position close to the surface,
ORIENT: align the instrument parallel/perpendicular to the surface,
INSERT: move the instrument tip along current tool axis through until touching the opposite inner cylinder wall,
PUNCTURE and HOLD: prepare and perform puncturing,
RETRACT: carefully withdraw the instrument tip in the direction of the tool axis,
DONE: move instrument roughly back to the starting position/away from the surface and report that the task was successfully performed,
ERROR: if an error is reported, either i) exit or ii) continue with the execution allowing the user to choose the next state.

Now, the pseudo XML representation is as follows:

```
<event type="btn1"
<event type="btn2"
<event type="err"
<event type="cnt"
----------------------------------------------
<basisVector opcode="bvX">
<vector> 1.0 0.0 0.0 0.0 0.0 0.0
<basisVector opcode="bvY">
<vector> 0.0 1.0 0.0 0.0 0.0 0.0
<basisVector opcode="bvZ">
<vector> 0.0 0.0 1.0 0.0 0.0 0.0
<basisVector opcode="bvA">
<vector> 0.0 0.0 0.0 1.0 0.0 0.0
<basisVector opcode="bvB">
<vector> 0.0 0.0 0.0 0.0 1.0 0.0
<basisVector opcode="bvG">
<vector> 0.0 0.0 0.0 0.0 0.0 1.0
----------------------------------------------
<state name="MoveTo">
  <description> Move the tool closer.
  <transition event="btn1" newState="Orient"
  <transition event="err" newState="Error"
  <constraint constr="bvX" weight="1.0"
  <constraint constr="bvY" weight="1.0"
  <constraint constr="bvZ" weight="1.0"
----------------------------------------------
<state name="Orient">
  <description> Orient the tool.
  <transition event="btn1" newState="Insert"
  <transition event="btn2" newState="moveTo"
  <transition event="err" newState="Error"
  <constraint constr="bvA" weight="1.0"
  <constraint constr="bvB" weight="1.0"
  <constraint constr="bvG" weight="1.0"
----------------------------------------------
<state name="Insert">
  <description> Insert the tool.
  <transition event="btn2" newState="Orient"
  <transition event="cnt" newState="Puncture"
  <transition event="err" newState="Retract"
  <constraint constr="bvZ" weight="1.0"
----------------------------------------------
<state name="Retract">
  <description> Move the tool away.
  <transition event="btn1" newState="Done"
  <transition event="err" newState="Error"
  <constraint constr="bvZ" weight="-1.0"
```


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The events are at this stage simulated by the user pushing one of the keyboard buttons. The task space of the robot is defined by a set of basis vectors. Theses basis vectors are then used in each of the states to define the preferred motion for the robot. At the run time, each of states sends the defined set of preferred motions to the low level Steady Hand controller which implements simple virtual fixture control law as described in Section IV-A.

IX. Conclusion

In this paper, a Human-Machine Cooperative System for augmented surgical manipulation tasks was presented. The current system consists of three levels: i) task graph modeling and generation, ii) task graph execution and iii) low–level implementation of control primitives. The motivation for such a design is that the complex surgical tasks are commonly repetitive and sequential in nature consisting of simple steps. In the current system, the transitions between these steps are driven either by surgeon's input or sensory information. Consequently, complex tasks are modeled using a set of basic steps or primitives where each primitive defines some basic type of motion (e.g. translational motion along a line, rotation about an axis, etc.). In terms of control, the system simply complies to the users input where a number of different constraints (virtual fixtures) can be imposed.

The system is currently validated using the JHU Steady Hand Robot as an experimental platform. The example task presented above is analogous to many minimally invasive or constrained motion tasks. For medical applications, there are currently no systems that integrate both the visual and users input to define control input to the robot. We believe that our approach, which uses virtual fixtures to define a set of preferred robot motions, offers a powerful theoretical ground that allows for easy verification of control policies. Our future research will consider further experimentation with skilled users for applications using clinical conditions.

Acknowledgment

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EXHIBIT B

UNITED STATES DISTRICT COURT

FOR THE DISTRICT OF NEW JERSEY

RAJESH KUMAR, :
:
Plaintiff, :
:
vs. :
: 2:12-cv-06870-KSH-PS
THE INSTITUTE OF ELECTRICAL :
AND ELECTRONICS ENGINEERS, :
INC., a New York corporation, :
:
Defendant. :

DEPOSITION UPON ORAL EXAMINATION
OF
DANICA KRAGIC

on

Monday, June 9, 2014
commencing at 9:36 a.m.

Taken at Stockholms tingsrätt:
Rådhuset
Scheelegatan 7
112 28 Stockholm
Sweden

Reported by: Thelma Harries, MBIVR, ACR

REDACTED

EXHIBIT C

Date: Fri, 01 Nov 2002 10:39:45 -0500
From: Greg Hager <hager@cs.jhu.edu>
To: Danica Kragic <danik@nada.kth.se>
Cc: burschka@cs.jhu.edu, bridget Nguyen-Ngoc <bridget@heart.cs.jhu.edu>
Subject: Re: appl

>I'll get back to you as soon as I get all my papers done. We'll
>decide on the date too. I still have to clear things with Henrik
>since he did not sound too happy about it yesterday. We have a new
>postdoc coming in January and Henrik wanted me to spend some time
>with her until she settles in. If I get there in Feb, I would
>probably stay until ICRA. I have some things attend in Austria in
>April but I'll probably postpone that.
>
>Can you give me some hint about what would you like me to work on?
>I browsed through some of the project-pages on the web so I got an
>idea about what's going on there .....
>
>Dani

I think the most logical thing is to work with us on assistance for micro-manipulation. This is generically along the lines of what I talked about at ICRA, but doing the human-in-the-loop version. You'd obviously be able to hit the ground running, there.

If you want a complete change of pace, we also have a project in vision-based HCI, and also a project in vision-guided mobile navigation. However, I suspect the largest impact would be on the vision-based manipulation side.

Let me know your preference and I'll expand on whatever theme it is ...

G

EXHIBIT D

Date: Thu, 09 Jan 2003 11:19:55 -0500
From: Greg Hager <hager@cs.jhu.edu>
To: Danica Kragic <danik@nada.kth.se>
Subject: funded proposal

Prof. Gregory D.
Hager Email: hager@cs.jhu.edu
Dept. of Computer Science Phone: (410) 516-5521
The New Engineering Building, Rm 324B FAX: (410) 516-5553
Johns Hopkins
University WWW:
http://www.cs.jhu.edu/~hager
3400 N. Charles St. Admin: (410) 516-6235
Baltimore, MD
21218 bridget@cs.jhu.edu

[Part 2, Application/ZIP 4.5MB.]
[Unable to print this part.]

Date: Tue, 14 Jan 2003 09:44:06 -0500
From: Greg Hager <hager@cs.jhu.edu>
To: Danica Kragic <danik@nada.kth.se>
Subject: Re: Dani project notes:

At 09:00 AM 1/10/2003 +0100, you wrote:
>Greg,
>I browsed through the papers you sent me. I like the idea and it is
>definitely something that I would like to work on. I will give it a
>more detailed look next week and get back to you with some questions
>(I'm leaving for Belgium for some EU meeting).
>
>Some general questions:
>- in terms of the scripting language - it seems that this would
>build on what I read in the Kumar's paper,

That is one possibility; not a necessity

>- I suppose that you already have some ideas of how you would like to
>do this - I can't really say that my experience in this field is
>great so I will do some reading,

I have various ideas and I suspect we can generate more

EXHIBIT
5
PENGAD 800-631-6989
6/9/14

>- do I remember well that you programming under Windows,

That may change and is not necessary unless you prefer it.

>- I saw in the proposal that you use C++, Java and Haskell - can
>you give me some more details what is used for what,

Forget Haskell; pick one of C++ or Java (probably preference to former)

>- who is currently working on this project,

Me, Russ Taylor, Allison Okamura, plus 3 or 4 grad students.

>Dani
>
>
>
>***
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EXHIBIT E

Simple Task-Level Augmentation of Microsurgical Scale Motion

Rajesh Kumar, *Member, IEEE*, Gregory D. Hager, *Senior Member, IEEE*, and Russell H. Taylor, *Fellow, IEEE*[×]

***Abstract*—Augmented surgical manipulation tasks can be viewed as a sequence of small, simple steps, with transitions between steps driven primarily by the surgeon's input. Each step can be abstracted as a controlled interaction of the tool/end-effector with the environment. In computing terms, each of the primitives is a predefined computational routine (e.g. compliant motion or some other "macro") with initiation and termination predicates. The sequencing of these primitives depends upon user control and effects of the environmental interaction. The basic research problems are: 1) to create an environment that makes it possible to easily and safely specify a sequence of control primitives; and, 2) to validate the efficacy of the resulting augmentation functions. Using the JHU "Steady Hand" robot as an experimental platform we investigate using such a sensor driven augmentation system for simple micrometer-scale manipulation tasks.**

***Index Terms*—Computer Aided Surgery, Hand Held Manipulators, Multi Sensor Systems, Telerobotics.**

I. Introduction

Dexterous manipulation is a key element in the speed, safety, and, ultimately, the success of most surgical interventions. The majority of surgical tasks involve light hand-held tools operated using both vision and force (including both tactile, and kinesthetic) information. While most interventions use both force and vision at some level, the availability and efficacy of both varies widely. In general, during coarse, large-scale manipulation forces from the tools are an important cue, but visual information improves both the speed and facility of manipulation. In contrast fine, small-scale manipulation (micrometer scale motions are common in several fields, for example eye surgery) is often almost completely visual, as the interaction forces between the tool and the environment are imperceptible to even a trained surgeon. Literature demonstrates [1-5], the lack of tactile information results in surgical procedures being longer and less accurate than if tactile information were present. This seems intuitive, though the data measuring, or correlating positional accuracy [6,7] and performance in conventional procedures are relatively scarce.

Several robotic systems have been envisioned as augmentation tools [8,9] for micrometer scale tasks. While the increasing need for augmentation at micrometer scales provides a clear opportunity for human augmentation, it also makes it clear that *different levels of augmentation are necessary at different stages and/or scales of surgical intervention.* Open problems regarding the development of any human-augmentation system for microsurgical tasks include 1) How might one develop a framework for human augmentation that varies its behavior in response to both the task context (e.g. scale) and the needs of the human within that context? And, 2) Does such a system provide "added value" to the human operator? Clearly, these two questions are closely inter-related and can only be answered through a cycle of engineering and empirical testing.

In this paper, we address both of these questions within the "Steady Hand" (Figure 1) manipulation [10] approach. The Steady Hand approach requires tools to be held simultaneously by the user and the robot, with the robot complying to forces applied to the tool. As such, Steady Hand manipulation is safe, as the surgeon has direct control of the manipulator, and thereby his or her accustomed surgical tools. At the same time, it is intuitive, as the surgeon not only directly manipulates those tools, but also receives direct force-feedback from the manipulator, thus "feeling" the manipulation much as one would during a large-scale surgical intervention. This approach (compared to more common tele-manipulation systems) is also more appealing because of its cost advantages.

Cooperative manipulation is a subject of active research for several applications, including industrial applications [11-14] Several basic research issues for cooperative manipulation, including virtual fixtures for augmentation [15], control modes for manipulation [16], and evaluation of comparative performance [9,17] have been explored in the literature. Here, we focus our attention on *task level* augmentation of micrometer scale surgical tasks. One of our basic hypotheses is that simple surgical tasks can be broken into a sequence of smaller, and simpler sensor guided steps. For each individual step, it is possible to provide an optimized augmentation based on the task context or objective for that step. In this paper, we present the development of a prototype system for augmentation of sequences of steps, and provide experimental

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results from this system applied in three different situations.

The remaining sections of this paper are organized as follows. The following subsections discuss prior art in hand held manipulators for robotic surgery, task-level augmentation, and performance evaluation. The next section describes our approach, hardware and software contained in our experimental platform, and instrumentation used for validation experiments. Section III discusses our prototype system, and details our initial experiments with this system. Section IV discusses the results of these experiments.

A. PRIOR ART

Recently, sophisticated systems[8,9,18] have been developed to assist, or augment human actions in unstructured environments, especially in medicine. In general, they are often used to reduce human involvement in a task (i.e. to act as tool or camera holder) than for their superior manipulation abilities however, in microsurgical tasks the converse is usually true. Although telerobotics is the more common paradigm, e.g., [19-27], several hand held manipulators [28,28,29] have been designed for use in surgical procedures. The converse of our experimental system, exoskeletons amplifying user input have been proposed by Kazerooni [30,31]

Analysis of robot systems operating in tandem with humans and extraction of some information from this cooperation is an active topic of research but existing work in methods for learning tasks focuses on determining force/position control parameters from a human worker's operation [32,33]. Kosuge [11,12] explored carrying cooperative tasks in industrial applications. Our group has also explored cooperative manipulation [15,34] modes of the "Steady Hand" robot.

Some surgical robotic systems, though not designed for micro-scale operations are also relevant as they are directly manipulated and use some level of task information for constrained control. Davies [28] designed hand-held manipulators with cutter end-effectors for orthopedic surgery applications. A PC is used for control in conjunction with a motion controller. The motion controller independently controls the motors. This system uses motion constraints to enhance safety. Constraints are stored as a lookup table to restrict compliant motion. Troccaz [35] designed a passive breaking system that allows dynamic constraints to be applied on a user's workspace.

Our work also relates to sensor-driven robotics and flexible automation research in several fields. Flexible automation has a wide body of relevant work. Taylor [36] analyzed automatic generation and analysis of task sequences, and task level planning in position space. Mason analyses robot control strategies, and the effects of constraints on such planning in velocity space. Taylor *et al* [37] also proposed a general purpose architecture for programmable automation research that uses task level programming. This architecture envisions, specification of a task as *data flow graphs* using computational functions and shared state variables. The computational functions could be high-level commands or *verbs*. The *verbs* may be simple motion specifications or termination conditions or compound *reflex graphs* composed of the verbs. An underlying layer also allows extension of the system by constructing new *verbs* from real-time subroutines that perform device I/O, control law, trajectory planning and such. The scheme we develop shares many similarities with this system.

Another system, proposed by Sanderson and Perry [38]describes multiple levels of descriptions for an assembly task. The highest level is an assembly algorithm, a sequence of operations performed on a physical part. This algorithm is described in a configuration-specific implementation using a sensing-representation-manipulation (SRM) description. A SRM description describes the system elements, as well as task description. The environment is also described in form of both physical representations, mapping sensor and control information to Cartesian levels, as well as feature space representations mapping control and sensor information to sensed features. This high level description is then translated to machine-level description for execution.

Recent work in hybrid systems [39-44]provides a formal basis for the study of systems composed of both discrete transitions and continuous behavior. As such, these studies provide an elegant theoretical basis for studying some of the formal properties of augmentation systems [45].

Other recent work in flexible task-level control includes feature based programming and its extensions (e.g. Eberman [46]), diectic strategies for specification of events (e.g. Pook [47]), vision guided processes (e.g. Dickmanns [48]) and sensor-based architectures for space and planetary robotics (e.g. Lee [49]).

II. OUR APPROACH

There are many generic manipulation tasks that may be augmented by a surgical assistant. Examples of such tasks are constrained and guarded tool motions (force constraints are especially hard to implement without augmentation and very common in practice), and tasks routinely performed by most surgical assistants today - camera holding, acting as a tool guide, and simple tool positioning. A flexible approach for performing these tasks with a cooperative robot would therefore benefit a wide range of surgical tasks.

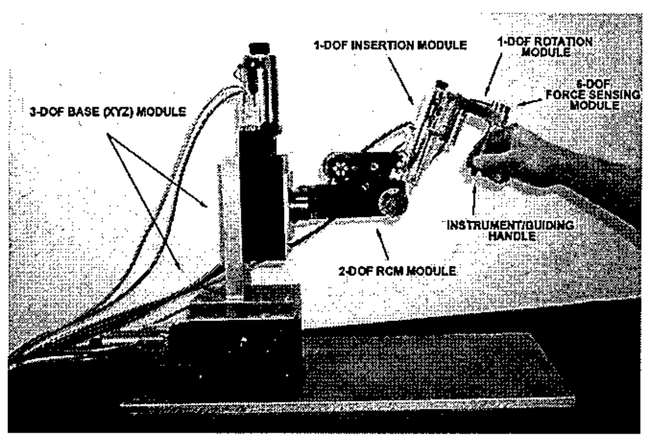

Figure 1: The JHU "Steady Hand" robot

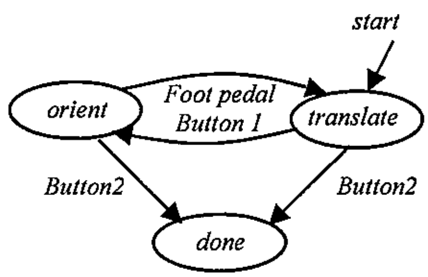

Figure 2: A simple three state graphs for basic modes of the "Steady Hand" robot.

As discussed earlier, our approach divides distinct portions of a surgical task into smaller parts, where detectable discontinuities require a change in the behavior of the robot. For example, moving from a portion of the task that involved positioning the tool to that requires orienting the tool or from an interactive part to a small monitored automated portion. These parts are represented as states in a task graph, with transitions connecting them in planned execution. This task representation for a given task is obtained by identifying distinct parts in the conventional approach for performing that task. Given that "Steady Hand" manipulation imposes an ordering on *planned* task execution (user only performs one action at a time with the manipulator), each of these parts can be implemented independently. Task execution is controlled by user input as well as by effects of interaction with the environment. In each state, sensing and measurement can modify the control mode and also effect state transitions.

For example, in simple "Steady Hand" manipulation, the user applies forces on the tool held jointly by the robot. The robot complies with the forces appropriately. A simple control law e.g. $x'(t) = K f(t)$ can provide stable control for the "Steady Hand" robot due to its highly geared actuators, and small manipulation speeds (mm/sec for coarse manipulation, and tenths of mm/sec for fine manipulation), where $x'(t)$ is the velocity, K is a gain factor and $f(t)$ is the user force vector after noise removal, and application of limits and thresholds. For force scaling control, the control law can be modified to $x'(t) = K \Delta f(t)$, where $\Delta f(t)$ is the appropriately scaled force error.

A basic cooperative task graph is one describing the basic modes of manipulation of the "Steady Hand" robot. Further, the robot is most often used in two distinct modes. The first mode (*translate*) uses the Cartesian base to reposition the tool tip and remote center of motion (RCM) point in the fine manipulation workspace. The second mode (*orient*) uses rotational and end-effector joints and is suitable for performing fine manipulation while keeping the RCM point fixed. In practice, the user may switch between the two modes by using buttons on a foot pedal. Another button on the pedal could signal termination of the manipulation task. This simple three state task graph appears in Figure 2. The two manipulation states in the task graph represent control modes discussed above. The third (*done*) represents termination of task execution.

The two control modes discussed above involve three degrees of freedom manipulation. There are several other modes of operation [15,16] for the steady hand robot. Other modes may require more or fewer degrees of motion, ranging from one degree of freedom modes for insertion of a tool or rotation about the tool axis, to six degrees of freedom for simultaneously orienting and positioning the tool. In additional, when the forces applied by the environment on the tool tip [34] are also used for control purposes, these modes have a variant where the scaled force error is used as the controlling input.

The above task is navigated by pressing buttons on a foot pedal. However, it is easy to imagine transitions being caused by interactions with the environment. For example, moving from a portion of the task with no contact to one in contact with the environment. Contact or impact can be reliably sensed automatically, and can be used for navigating the task. The transition between states can be dependent upon normal and planned events, such as force, position or velocity thresholds or ranges, and abnormal events such as hardware or software failure. It may also be possible to analyze the user input to identify his intention to transition[50] to a different mode using techniques such as Hidden Markov Models (HMMs) [51].

To demonstrate the application to simple surgical tasks, consider the following example task. The task of placing a tool through a port (small incision or hole) has both coarse manipulation (positioning and orientation leading to the port) and fine manipulation (inside the port) and is composed of the following steps: *a)* positioning the tool at the port, *b)* orienting it such that it can be inserted, *c)* insertion of the tool, *d)* adjusting the orientation of the tool towards the placement site viewing through the visual feedback device (microscope in the eye, video feedback in laparascopy etc), *e)* approaching the site, and, *f)* achieving target location or contact. This task involves both fine and coarse manipulation, and is a common minimally invasive task.

Each of these components requires the robot to modify its control mode. Positioning requires translation, while orientation requires only rotational control. Further, motion outside the port can be faster than inside, where safety constraints and smaller workspace may require slower motion to avoid errors. This can be implemented by appropriately changing the gains in the control law to provide a stiff or compliant manipulator. Each part of the above task can be implemented as a state in a task graph. An explicit task representation provided by the user for a specific task includes inputs, safety limits and thresholds, and control mode

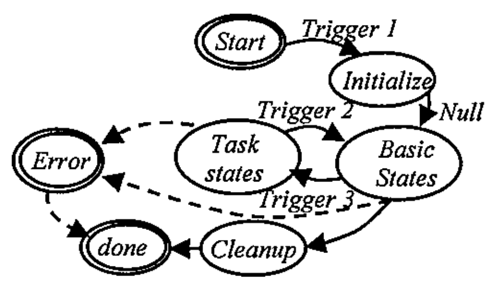

Figure 3: System Control flow for our augmentation system (error transitions are shown as broken lines)

parameters. Here, we explore three simple tasks for which a task graph representation can be easily obtained.

A specification language was developed to implement task graphs for augmented tasks. This specification language allows construction and execution of graphs on pre-defined or composed primitive control modes and triggers. A program consists of forward declaration of its actions (states in the task graph), and events (transitions in the task graph), a task section for initializations and global events (transitions from all states, such as errors or limits), and action and event definitions. The specification language supports common basic types, as well as types needed for linear algebra. Most common algebraic and linear algebra operators and mathematical and trigonometric functions are also supported. The robot and several additional sensors are part of the specification language and are tracked as system variables.

```
action translate,orient;
event translate2orient,
      orient2translate, event2quit;
task simpletask {
      BiasUserForces;
      EnableForceLimits;
      Enable;
} events{ on event2quit done}
action translate{
      ComplyBaseJoints;
}events{on translate2orient orient;}
action orient{
      ComplyArmJoints;
}events{on orient2translate
        translate;}
event event2quit {return button2;}
event translate2orient
      {return button1; }
event orient2translate
      {return button1; }
```

Figure 4: An implementation of the three state basic task graph. The two actions invoke routines implementing the basic control modes of the robot, and the events monitor the buttons on the foot pedal.

Actions are composed from sensing and manipulation primitives. In the above example (Figure 3, task graph of Figure 2), the actions are composed of a single "move in compliance to forces" primitive with different parameters. *Translate* uses the translation stages of the robot to provide XYZ positioning where as *orient* uses two rotational degrees of freedom (X,Y) about a mechanically constrained remote center of motion(RCM).

The basic functionality of the system (Figure 4) allows the user to manipulate the robot in its basic control modes. The task states represent the task graph for the current task. The user can choose to execute the task graph or halt execution. During the task graph execution, completion of the task returns control to basic system states. The basic set of states includes initialization and cleanup, a manipulation set, data collection set, and safety and error checking. The system basic states are sleep, move in compliance to forces, and error states. The data collection set includes a single dump state. Safety events include workspace and force limits, and hardware and software errors.

III. EXPERIMENTS

We have used the specification environment together with the afore-described software and hardware to validate the task-graph approach to surgical augmentation. In this section, we present the results of three experiments.

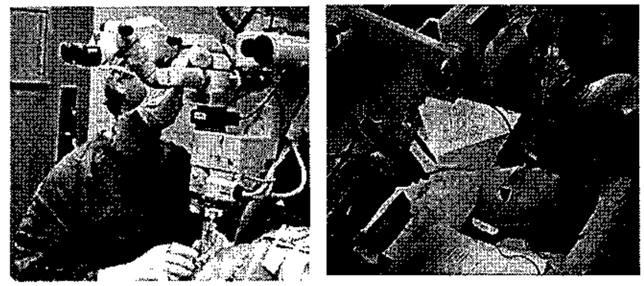

Figure 5: Clinical setup for eye surgery and experimental setup for our experiments)

A. EXPERIMENTAL ENVIRONMENT

Microsurgical procedures are performed by a surgeon viewing the surgical site through a high-power stereo microscope (Figure 5), and operating with hand held tools. Arm rest support is often provided for reducing hand tremor. Our experiments simulate this working environment, and in addition, the tool is held both by the user and the "Steady Hand" robot.

The "Steady Hand" robot [10] (figure 1) is a 7-degree-of-freedom manipulator with XYZ translation at the base for coarse positioning, two rotational degrees of freedom at the shoulder (the RCM linkage[52]), and instrument insertion and rotation stages. A force sensor is built in the end-effector for sensing user forces, and additional sensors can be attached at the tool-tip module for sensing environment forces. The robot has a remote center of motion and an overall positional accuracy of less than 10 micrometers.

A GRIN lens endoscope (Insight IE 3000, Insight Instruments Inc.) was used for imaging. It was mounted on the insertion stage of the steady hand robot with the ergonomic handle used for sensing the manipulation forces attached at an offset using an adapter. Custom built strain gauge based force sensors as well as commercial (ATI Industrial Automation Inc, Bokam Engineering Inc,) force sensors were used for force sensing.

B. EXPERIMENT 1

The "peg in hole" task has been a common task for evaluation of comparative performance. Salcudean et al [17] use this task to evaluate the performance of a tele-operated microsurgical robot Similarly, Das et al [9] have conducted a pilot study to evaluate the RAMS microsurgical system against conventional microsurgical performance. We have performed similar experimental studies to evaluate the effectiveness of "Steady Hand" augmentation in comparison to simple compliant motion and un-augmented free hand performance.

In these experiments, a ball was sliced and ports constructed to reflect distances similar to the eye to simulate cannulation of a retinal vessel (which is a port tool placement task). This ball was attached to a data surface containing 100 micrometer holes separated by 2mm. The ergonomic tool handle for the "Steady Hand" robot was mounted with a 1 mm shaft and 50 micrometer tip wire for the tool. The goal of the experiment was to touch the bottom of the hole inside the "eye" without touching the sides Automatic electrical contact sensing was employed to detect contact between the bottom of the holes (*success*) or the sides of the hole or elsewhere on the surface of the data surface (*error*). This port tool placement task is essentially a modified "peg in hole" task with additional constraints at the port.

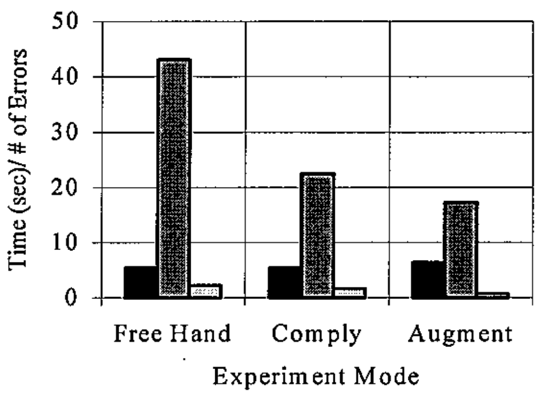

Figure 7: Comparative performance in the simulated vein cannulation task. Average times for three users in three different control modes. The time outside the port (left) is similar, but the fine manipulation time inside the port (middle), and the number of errors(right) decrease with simple compliance modes as well as with task level augmentation.

The initial results[53] (figure 7) suggest performance superior to free-hand execution, although further systematic evaluation is needed to quantify this improvement.

Here, we report on initial experiments to test the feasibility of using task-graph enhanced augmentation for performing microsurgical tasks. For this purpose two microsurgical tasks were selected. The first task is a constrained needle placement task that presents many of the fine manipulation difficulties encountered in eye surgery. The second task is a constrained motion task, for constructing a composite image (mosaic) of the retina with a high resolution imaging endoscope mounted on the steady hand robot

C. *EXPERIMENT 1*

Our first experiment simulates treatment of a retinal vein occlusion by local application of anti-coagulants. A retinal vein occlusion is essentially a blockage of the portion of the circulation that drains the retina of blood. With blockage of any vein, there is back-up pressure in the capillaries, which leads to hemorrhages and also to leakage of fluid and other constituents of blood. Usually, the occlusion occurs at a site where an artery and vein cross. These occlusions may affect functioning of large portions of the retina, or even entire retina if the central retinal vein is involved. The diagnosis of a retinal branch vein occlusion poses little difficulty to an ophthalmologist who will detect dilated blood vessels, hemorrhages, and swelling along the vein. The blockage may sometime cause the involved capillaries cease to function and close off.

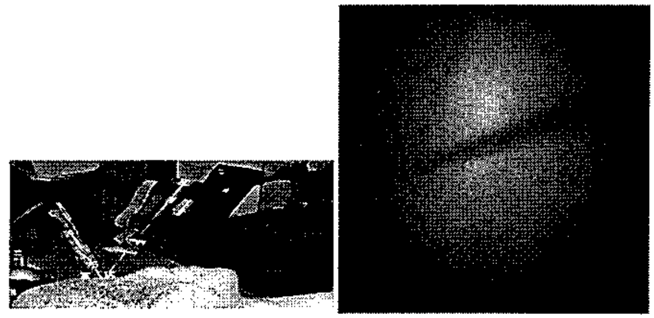

Figure 6: Experiment setup for retinal vein cannulation (left). A porcine eye is setup in a foam face. A micro needle is mounted on the ergonomic handle. The GRIN endoscope is used for visual verification. The microscope used by the user is visible at the top of the image, and the micro needle positioned in a retinal vessel (right).

There is no commonly accepted medical treatment for retinal vein occlusion. Common anti-coagulants (e.g. heparin, coumadin and aspirin) have not been shown to be of value in preventing occlusion or managing its complications. Further anti-coagulants may be associated with systemic complications, and can be prescribed only in specific clinical circumstances, for example for patients with known clotting abnormalities. Local application of anti-coagulants promises of treatment of vein occlusion. However due to the size of the blood vessels, placing a micropipette in an occluded blood vessel for the duration of the dissolution of a clot has proven to be extremely challenging.

For this experiment (see figure 6), directed at positioning a micropipette in the occluded vessel, a porcine eye was mounted naturally in a face phantom and a MEMS micro-needle (XACTIX Inc., Pittsburgh, PA) was mounted on a 2mm shaft to be used as the probe. The micro-needle mimics a micro-pipette used in experimental vein cannulation treatment. Although they can not deliver anti-coagulants, micro-needles allow us to prototype experiments for evaluating augmentation strategies without added complications from the treatment delivery instrumentation. The lens of the porcine eye was removed to improve access to the retina. The GRIN lens endoscope was positioned to image the target blood vessel for visual verification.

The task graph appears in Figure 8. The user moves the robot end-effector to the port, adjusts the orientation and position, inserts the tool when appropriate, and makes contact. On contact, the robot can either perform the puncture automatically, or the user can perform the puncture using forces sensed by the tool tip sensor. The force profile of a puncture shows a detectable force peak (10s mN) and much smaller forces after the puncture. Following the puncture, the user would hold the instrument in place for therapy delivery,

and then retract it with the same trajectory as the insertion. Any error inside the organ, also allows the user to retract the tool. This task graph is also navigated with a foot pedal.

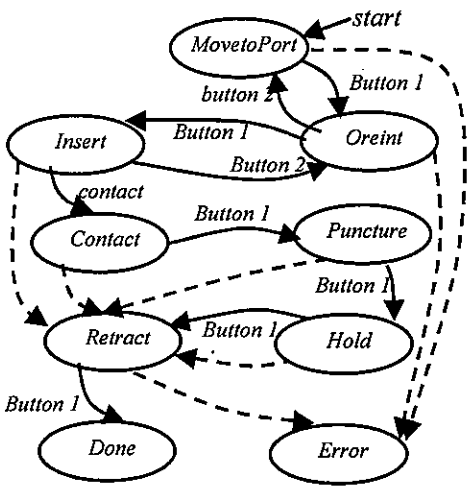

Figure 8: Task graph for vein cannulation (error transitions are show with broken lines)

The task graph in Figure 8 was used on a small hollow plastic tube, essentially to verify contact, and puncture routines. The single force peak, in 10s mN is sufficient to detect puncture automatically by tracking the monotonous increase in force after the contact and waiting for the sharp drop in the contact forces. This simple strategy worked well in practice for automatic punctures.

In-vitro experiments with porcine retina proved harder. A typical targeted retinal vessel is 100s micrometer, and the lack of blood flow in the porcine eyes reduces the inner diameter to very small values. Further, it also reduces any resistance the passing blood would have provided to the needle. As a result, our first experiments only saw intermittent success in puncturing the outer vessel wall only, and not puncturing the retina. One of the reasons for the failure was the near vertical approach in these experiments. Surgeons use close to tangential approaches when inserting probes in blood vessels. Similarly, when the approach path of the robot is near tangential or at a small angle, higher success rates are observed. However, the lack of blood flow and partial collapse of the blood vessels remains a problem. These problems can be resolved if an animal model is used instead.

Figure 9: Experimental Setup for imaging a porcine retina.

Diagnostic retinal imaging presents a very good application of our system. Retinal fundus images are a common mode of diagnostic imaging for the eye. Endoscopic imaging using small probes (e.g. GRIN lens endoscope, Insight Instruments Inc) can be used to provide higher resolution imaging of small regions of interest. However, these probes only image a very small region (~mm^2) and need to be held at similarly small distance from the retina. Creating a compound image of the anatomy without robotic assistance is nearly impossible. Using robotic augmentation, this is a constrained guidance task. Further, irregular regions of interest can be selected.

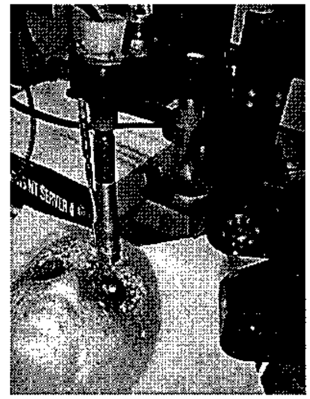

Figure 9: Experimental Setup for imaging a porcine retina.

The goal of our second experiment was to completely image the selected portion of the retina with the GRIN lens endoscope. in an efficient way. If the region of interest is a block region, a simple strategy could be a spiral movement starting with the center of the region of interest. On the other hand, if we consider imaging along a retinal vessel only, then moving in a grid fashion to capture long strips is a possibility. In either case, the user selects the amount of motion between the consecutive images to ensure properly overlapping images.

For this experiment, the GRIN lens endoscope was mounted on the insertion stage of the steady hand robot. The ergonomic handle used for sensing the manipulation forces was mounted at an offset using an adapter. This configuration can also be

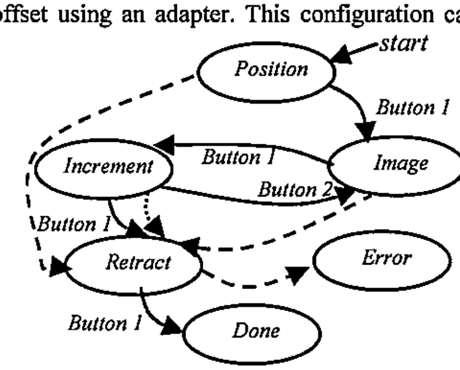

Figure 10: Task graph for creating mosaics (error transitions are show with broken lines).

used to mount endoscopes of a larger size for neurosurgical tasks. A porcine eye was positioned naturally in a phantom head, and a port was created in the eye for positioning the endoscope such that the RCM point was at the port. In some cases, the eye's lens was removed to expose the retina and provide better access. The experimental setup appears in Figure.9

A task graph for the mosaic task appears in Figure 10. The scope is first positioned in the eye and one of the above augmentation strategies is activated. The user then moves the robot to the next step, images the region and repeats the process until the entire region is imaged. The scope is then retracted to finish the task.

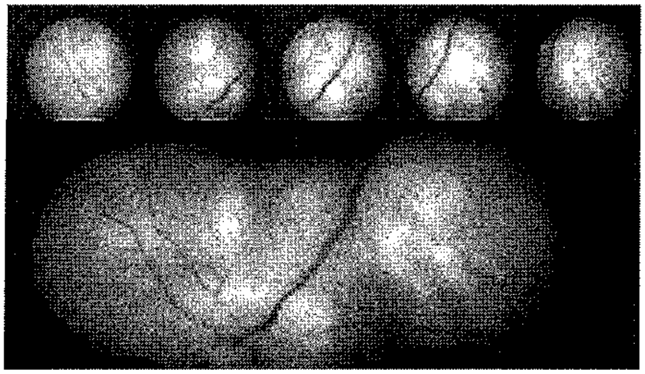

Figure 11: A series of images and the processed composite

The images and the robot position at which they are taken are then used to construct the composite image. Because of the accuracy of the robot, even a simple reconstruction procedure provides good high-resolution montages. An example of a line of 5 images and the corresponding composite image appear in Figure 11.

IV. DISCUSSION

We report on three novel applications of simple task-level augmentation. Our system utilizes the sequential nature of the execution of augmented single instrument tasks. Note that since this manipulation uses the "steady hand" approach, this is inherent. The example tasks chosen above is analogous to many minimally invasive, or constrained motion tasks.

Initial and encouraging experimental results are reported here, but further experimentation is needed with skilled users in conditions even closer to clinical conditions to validate these results. The tools used in these experiments, are either used clinically {such as the endoscope and the foot pedal}, or simulate current surgical instruments closely. So our *in-vitro* experiments should be easily extensible to *in-vivo* environments for further evaluation.

Alternative mechanisms for state transitions (pause in motion, automatic detection by comparison of change in state <force,position, velocity>) are available but they are yet to be evaluated. A simple interpreted execution environment was built for the purposes of our experiments. The data collected is processed offline, and is not used by the next execution of the same task graph. User profiles for task parameters is another useful feature currently not implemented. The execution environment can be extended to include support for process learning. It also needs better visualization of the data collected. The current system is limited to single hand held instrument tasks, but it could be extended for multiple robots, and tools.

Hidden Markov Models (HMM) and associated search algorithms can be used to integrate probabilistic determination of users intentions from the sensor input. Hannaford [51]among others have used HMMs extensively to model and analyze teleoperated tasks. For our purposes, a HMM is a finite state machine augmented with probability distributions for making transitions and observing state. The HMM could be initialized with the task graph. The probability distributions are initialized with nominal values. A set of trials could be performed for training the HMM. This trained HMM can then be used for experimental purposes. This is a simple extension of our work. Hundtofte et al [31] report initial work in this direction from data obtained from our system. Pook [47] reports similar work for using a simple sign language to control a manipulator with good success in segmentation of user input.

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EXHIBIT F

Dani project notes:

Objectives: To produce a scripting language for multi-step augmentation procedures. More specifically, to develop a way of specifying parameterized hybrid system graphs, where nodes in the graph correspond to continuous control objectives, and transitions are triggered by "guards" or similar discrete transition conditions.

Another aspect of this scripting language is to use it as a "model" for what we expect to see in a procedure. We are currently using HMM's to model different types of motion or action.

Context: We are interested in augmenting users performing moderately complex surgical operations. Examples are retinal vein cannulation and retinal membrane peeling. Both of these involve different types of augmentation to enhance precision, speed and/or safety at various steps of the procedure. We are also interested in small lot manufacturing of very small and delicate mechanisms (MEMs).

What needs to be done?

1. Implementation and stabilization of assistance modes. The theory is essentially there; most of the systems structure is there; needs to be complete and tested by someone knowledgeable. Students and engineering staff are available to help to get the implementation together.

2. Scripting language design and implementation. Ideally, this would make it easy to put a "wrapper" around different control elements and "glue" them together, possibly with some free parameters.

3. Develop demonstrations using a stereo operating microscope, the steady-hand robot, and surgical tools. Likely targets are peeling tissue from an egg, and poking blood vessels in pig eyes.

What are the research questions?

One set of research questions resolves around the design of the scripting language, and in particular how it relates to the task graph model. For example, does it make sense to specify the "high level" structure in terms of a graphical model, and then "edit in" the low level structure; can the language be so structured that this makes sense?

Another set of questions revolves around the use of sensing, particularly vision, in these scripts. For example, there is a fundamental compatibility between the type and geometric arrangements of features acquired from the visual stream, and the degrees of freedom that can be controlled in the assistance system. How does this all get worked out in an elegant and consistent fashion?

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Another direction would be the use of surface information and the incorporation of "no-fly zones" or "sticky surfaces" in the model; this would involve incorporating the real-time stereo algorithms.

What are the possible outputs?

1. A working system at some level
2. A paper on the system/language design
3. More technical papers on structuring families of sensor guided augmentation primitives
4. A discussion of cooperative control in a sensor-guided context, where the user works with the system to both specify and achieve objectives.

Relevant Papers:

HMCS proposal
Kumar TRA submission
Recent ICRA and IROS papers
Markov modeling papers

EXHIBIT G

SUBMISSION NOTICE

Date: Sun, 16 Mar 2003 12:10:39 -0500 (EST)
From: Iros 03 <iros03@ecn.purdue.edu>
To: danik@nada.kth.se
Subject: IROS03 Submission Received

Thank you for submitting to IROS03! We have sucessfully received your paper, which was assigned the following confirmation number:

Confirmation#: 695

Appended below is the information we recorded.

The Program Committee will review your paper shortly. Around June 10, 2003, you will receive their decision, accompanied by the detailed paper reviews.

If you have any questions or problems, please contact csglee@purdue.edu. Please be sure to include your paper's confirmation number in all correspondence.

Thanks again for submitting your paper. We look forward to having a great IROS03!

Sincerely,
Junku Yuh
Program Chair, IROS03

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Information Received from Submission 695
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You must not lose your ID/confirmation number. Without your ID number, you will not be able to retrieve your password. You will not be able to login and resubmit. You must not lose this number. Please keep this email and write your ID number in a safe place.

Confirmation Number: 695
Password: tanja310776

Full Name: Danica Kragic
Email: danik@nada.kth.se
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Title: Task Modeling and Specification for Modular Sensory Based Human-Machine Cooperative Systems

Keywords:
HumanRobotAugmentation
MedicalRobots

Abstract:
This paper is directed towards developing of \textit{Human-Machine Cooperative Systems} (HCMS) for augmented surgical manipulation tasks. These tasks are commonly repetitive and sequential consisting of simple steps. The transitions between these steps can be driven either by the surgeon's input or sensory information. Consequently, complex tasks can be modeled using a set of basic steps or primitives where each primitive defines some basic type of motion (e.g. translational motion along a line, rotation about an axis, etc.). In terms of control, the system can simply comply to the users input or use, for example, visual input.

In particular, the research problem considered here is the design of a system which allows for simple design of complex surgical procedures given a set of basic primitives. We consider three system levels: i)~task graph generation which allows the user to easily specify or model a task, ii)~task graph execution which executes the task graph, and iii)~at the lowest level, the specification of primitives which allows the user to easily specify new types of primitive motions. The system is currently validated using the JHU ``Steady Hand'' robot as an experimental platform.

File Name: KHiros03.pdf
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Length: 186426
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EXHIBIT H

Danica Kragic
Olof Palmes Gata 14
111 37 Stockholm
mobil: 070 467 4536

Stockholms Tingsrätt
Avdelning 4

Mål nr
T 14085-13 Enhet 42

Jag har mottagit Ert brev om att yttra mig över framställan av handlingar beträffande rättslig hjälp från domstolen i USA, United States District Court, District of New Jersey.

Jag är villig att lämna ut angivna handlingar som är förklarade i detta brev samt inkluderade på det bifogade USB minnet.

Med vänlig hälsning,
Danica Kragic

According to the point 10 in the Request document, documents or other property to be requested are as follows:

1) Documents relating or referring to each of the subjects in Section 11 of the Request document.

   Answer: See detailed answers according to all the points requested in Section 11 below.

2) Documents related or referring to the Article, including source files and source material for figures appearing therein and grant applications relating thereto.

   Answer: All the material for the IEEE IROS publication (Article) can be found on the provided USB memory device under directory IEEE_IROS_2003. Background material leading to the Article is provided in directories Own_Prior_Material and Background_document on the USB memory device.

3) Documents relating or referring to the doctoral thesis "An Augmented Steady Hand System for Precise Micromanipulation" by Rajesh Kumar, published in April 2001.

   Answer: The material in which the thesis was cited is provided in directory Background_documents on the USB memory device.

4) Documents sufficient to identify when Dr. Kragic was present at John Hopkins University

   Answer: A copy of the ticket and my passport with the visa is attached under directory Passport-Visa on the USB memory device.

5) Documents sufficient to identify when the Article was submitted to IEEE for publication.

   Answer: Emails confirming this can be found under directory IEEE-IROS-2003-communication on the USB memory device.

Section 11 from the Request document lists questions to be put to the person to be examined or statement of the subject matter about which is to be examined:

1) Preparation, creation and authorship of the article "Task Modeling And Specification for Modular Sensory Based Human-Machine Cooperative systems", by D. Kragic and G. Hager, published by the IEEE (hereinafter, "the Article"), including sources of the Article and previously published articles, thesis and grant proposals.

   Answer:
   - **The final version of the article and all the source files are provided in the directory IEEE_IROS_2003. The article has been written using Latex software and the figures have been drawn using Xfig software.**
   - **The dates of the submission, acceptance and final submission are provided in directory IEEE_IROS_2003_communication.**

- **Email exchange with Dr Gregory Hager prior and until the Article submission is provided in directory Relevant-Email. In the same directory, there is a document including email exchange with a colleague in Sweden that documents the developments of the code provided in the directory System on almost daily basis.**
- **The work published in the Article also relates to my previous work documented in articles and thesis prior to my arrival to John Hopkins. These include figures drawn by Xfig and also ideas about task decomposition (several of the publications including my PhD thesis from 2001). All these are included in Own_Prior_Material.**
- **Material that was available to me prior to arrival to Johns Hopkins and that is mentioned in the email exchange with Dr Hager are provided in directory Background_documents.**

2) Description of the experimentation performed in the connection with the Article, and the nature of the work Dr. Kragic or others performed at Johns Hopkins University in connection therewith, including the dates such work was performed.

   Answer: The example of the system as described in Section VIII of the Article shows the scenario and implementation of the XML system. Graph generation was performed using the developed GUI. All these have been implemented under Linux on my personal laptop from the beginning of my arrival to Johns Hopkins. All source files for this are provided in the directory System on the USB memory device. CVS software version control was used to track the development of the system and all the relevant dates for the development of the code can be found in the subsequent directories.

3) Dates of Dr. Kragic's arrival and departure at Johns Hopkins University.

   Answer: A copy of the ticket and my passport with the visa is attached under directory Passport-Visa on the USB memory device.
   I arrived on February 5th 2003 and left on May 3rd 2003. The relevant flight ticket and the email exchange are included in the directory.

4) Date(s) of submission of the Article to IEEE.

   Answer: Emails confirming this can be found under directory IEEE-IROS-2003-communication on the USB memory device.

5) Relationship between the IEEE article and subsequent versions of the Article submitted to other publishers.

   Answer: Two subsequent publications are provided in directory Subsequent_publications. These include parts of the Article related to task graph generation and definition of virtual fixtures.

EXHIBIT I

```
  <?xml version="1.0" encoding="UTF-8" ?>
- <procedures xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
   xsi:noNamespaceSchemaLocation="procedures.xsd">
 - <!--

       If you exchange the following two lines with the top lines in the file
       you will use DTD checking instead
       <proccedures>
       <!DOCTYPE procedures SYSTEM "procedures.dtd">
       First we define the different events that we have. This
       definitions will be used to instantiate object that can be used to
       monitor that particular event. That is , we might create and object
       that listens for someone pressing a button. When we run the system
       pressing the button will make this event be sent to the state machine
       that will pass it on to the current state that deals with it. NOTE
       that we do not tell how the different components are used here, we
       leave that for the state machine (the procedure).
   -->
   <event type="button1" />
   <event type="button2" />
   <event type="error" />
   <event type="contact" />
   <!-- Define the state machine for a procedure here   -->
 - <procedure name="pigEyeOperation">
     <description>Abuse the eye of a pig</description>
   - <state name="moveTo">
       <description>Move the tool closer to the pig eye</description>
       <transition event="button1" newState="orient" />
       <transition event="error" newState="error" />
     </state>
   - <state name="orient">
       <description>Orient the tool for best angle close to the eye</description>
       <transition event="button1" newState="insert" />
       <transition event="button2" newState="moveTo" />
       <transition event="error" newState="error" />
     </state>
   - <state name="insert">
       <description>Insert the tool into the eye</description>
       <transition event="button2" newState="orient" />
       <transition event="contact" newState="puncture" />
       <transition event="error" newState="retract" />
     </state>
   - <state name="puncture">
       <description>Puncture the eye</description>
       <transition event="button1" newState="hold" />
       <transition event="error" newState="retract" />
     </state>
   - <state name="hold">
       <description>No clue</description>
       <transition event="button1" newState="retract" />
       <transition event="error" newState="retract" />
     </state>
   - <state name="retract">
       <description>Move the tool away from the eye</description>
```


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```
      <transition event="button1" newState="done" />
      <transition event="error" newState="error" />
    </state>
  - <state name="done">
      <description>Maybe clean up stuff...</description>
    </state>
  </procedure>
</procedures>
```

EXHIBIT J

```
#include "MoveTo.hh"

#ifndef DEPEND
#endif

using namespace CCA;

MoveTo::MoveTo()
  :State("MoveTo")
{}

void MoveTo::start()
{}

void MoveTo::stop()
{}

int MoveTo::handleEvent(Event &e)
{
  return 0;
}
```

EXHIBIT K

Confidential

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EXHIBIT L

1 Motivation and Overview

Computers today have evolved to become a pervasive, essential, *personal* tool as the internet, electronic mail, and the world-wide web become a part of our social fabric. Much of the population now interacts directly with computers to perform myriad "information tasks" that once would have been difficult, impossible, or even unimaginable for the average person. Computers working with people have a similar potential to fundamentally alter the way that humans interact with the *physical world.* Already today, teleoperated systems for remote exploration and manipulation are used undersea [1, 2, 3], human extenders [4, 5] suggest a future where physical strength will be amplified through machines, and Sony's AIBO signifies the beginning of a wave of new interactive, autonomous, robotic toys [6].

In this proposal, we focus specifically on developing design principles that will enable robotic mechanisms coupled with computation to enhance human capabilities at highly skilled *dexterous manipulation tasks.* Consider, for example, a human performing a typical mechanical assembly task. Such a task requires a high degree of basic sensory-motor coordination, high-level knowledge of the assembly task to be performed, and a degree of judgment as to how best to apply common manipulation "idioms," e.g. aligning parts, threading screws, and so forth, in order to accomplish the task. Now, imagine performing *microassembly* [7, 8] where forces are nearly imperceptible, depth perception and field of view (through a microscope) are limited, and many macro-scale manipulation idioms simply cannot be applied due to human sensory-motor limitations. Skilled technicians learn to use other sensory cues, to better control their movements, and ultimately develop new strategies to attack these problems. Although humans have a great ability to adapt to these novel and challenging circumstances, there are physical and mental limits that cannot be surmounted.

Preliminary evidence [9, 10, 11, 12] suggests that humans operating *in collaboration* with robotic mechanisms can surmount these barriers [13, 9]. On the one hand, such systems extend the traditional notion of Human-Computer Interfaces in that they include sensing and actuation interfaced to the external world as well as to the human operator. Yet, while relying on robotic speed and precision, they avoid the difficulties of full autonomy by retaining the human component "in-the-loop" for essential decision making and/or physical guidance.

We therefore propose a broader study of *human-machine collaborative systems* (HMCS)—systems that combine robotic sensory-motor capabilities, computation, and human judgment to enhance and extend human dexterity.

1.1 Background and Related HMCS Work

Human-machine collaborative systems are designed to directly assist a human engaged in physical manipulation of the environment. Table 1 depicts several existing experimental HMCS systems classified by their four primary input/output components: user input, user feedback, sensor input, and system output. User input is the way the user's desired action is sensed by the system. For example, the user can provide a position, force, or verbal "command." User feedback is the information the user receives from the system, such as visual, force, or audio information. Sensor input includes, for example, force or video data used to control, define, or constrain robot or user actions. Finally, system output is the way that the system interacts with the environment that is being manipulated. Position and force are the two most common outputs, as physical motion or work are usually desired. The relationship between these four system components is determined by various control laws that result in different system behaviors as needed for the specific applications context.

A fundamental premise of our project is that an appropriately architected human-machine system can exceed the capabilities of either human or machine alone. This idea is closely related to traditional teleoperation which dates back to the 1940's. In teleoperation, much of the work has been related to the problem of "remotizing" the operator and dealing with the associated problems of time delay, sensory feedback and so forth [21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32]. Our goal is not to physically separate the operator and the robot, but rather to provide varying levels of *operator assistance* depending on context.

Sheridan [33] introduced Supervisory Control as a paradigm for human-machine collaboration. Supervisory control postulates remote control where the human performs "high-level" planning, error recovery, and verification while a remote manipulator performs basic parts of the task autonomously. While clearly relevant to HMCS, supervisory control seeks a stronger separation between human and machine than convenient for many dexterous manipulation tasks (and indeed stronger than any of the systems shown in Table 1).

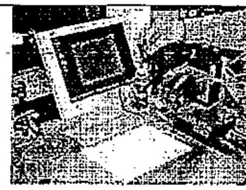
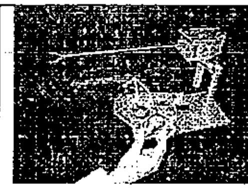
				
Example	JHU Steady Hand Robot (SHR) [14]	JHU SHR with virtual fixtures [15]	UW Force reflective endoscopic gripper [16, 17, 18]	Immersion 3GM for virtual surgery [19, 20]
User Input	force	force	position	position
User Feedback	position	position	force	force
Sensor Input	none	vision	force	position
System Output	position	position	force	virtual position

Table 1: Examples of human-machine collaborative systems. The first column shows Dr. John Niparko, head of the JHU Otolaryngology department, testing the JHU Steady-Hand Robot on an inner-ear specimen. The second shows an example of the Steady-Hand Robot implementing a vision-guided virtual fixture. The third shows the UW Biorobotics lab force-reflective gripper, and the final column shows a virtual master-slave system.

Shared and traded control [34] can be viewed as an HMCS for manipulation tasks in which some degrees of freedom are controlled by machine and others by the human (shared control) or in which control of all degrees of freedom alternate between human and machine (traded control). Our notion of HMCS design includes ideas from shared and traded control, but will also address the broader question of modeling manipulation activities consisting of multiple steps, and validating those models against human performance data.

In many cases there is no reason to separate the human and the robot. *Direct augmentation systems* physically share tools between a human and a robot. The JHU Steady-Hand Robot shown in Table 1 is an example of such a system. Other examples of non-teleoperated cooperative manipulation are provided by exoskeletons developed by Kazerooni [35, 36, 37] and a recent assistance device developed by Fanuc [5]. However, these system focus on amplifying strength, not dexterity.

HMCS can amplify human ability in many ways. The notion of "virtual" or "synthetic" fixtures [38, 30, 31, 39, 32, 40, 41] provide for cooperative control of a manipulator by "stiffening" a hand-held guidance mechanism against certain directions of motion, defining impedance planes [38], or by constructing "virtual magnets" that guide a user toward contact [30]. Studies have indicated that user performance on a given task can increase as much as 70% with the introduction of guidance using fixtures [38]. Likewise, recent preliminary tests using the Johns Hopkins Steady-Hand Robot [14] have suggested that the appropriate use of virtual fixtures in vitreoretinal microsurgery could have a significant impact on both speed and efficacy of such procedures [11]. Appropriately applied force or position scaling are yet another means of enhancing human dexterity [42, 12]. Recent studies suggest as much as a ten-fold increase in the time taken by microsurgical procedures is due to the loss of haptic feedback [43, 44, 45].

While many of these latter ideas bear on HMCS in one way or another, most have been developed in isolation and/or for a specific problem setting. Our proposal addresses the development of these ideas as general computational tools, the incorporation of techniques for *modeling* human skilled dexterity and, ultimately, the means for *validating* the performance of a given Human-Machine Collaborative System.

1.2 Experimental Setting

The broad goal of our proposal is to investigate human-machine cooperative execution of small scale, tool-based manipulation activities. Examples of such activities include common assembly tasks, e.g. fine scale machining and assembly, soldering of small parts or wires; micro-assembly tasks such as assembling LIGA

parts [13, 7, 8], and examples from biology, including microsurgical suturing or cannulation, cell manipulation, and so forth.

We will focus our experimental efforts on tasks taken from the domain of microsurgery. Briefly, microsurgery is a broad area of clinical practice with several sub-specializations, but generically involves a surgeon looking through a microscope (or similar imaging device) while manipulating tissue using highly specialized tools and skills. The focus of this proposal is not microsurgery per se; rather, our choice of microsurgery is motivated by several factors. First, it is a real problem: two limiting factors in current microsurgical practice include [46, 43, 47, 44, 45]: 1) sensory limitations — surgeons have little or no haptic perception and limited depth perception, and 2) human tremor and drift which limits the size of structures to be manipulated. The ability of microsurgeons to deal with this limitations defines the current state of the art in microsurgery. Second, the challenging nature of most microsurgical procedures has forced surgeons to refine them into a set of simple, linear, quasi-static steps, each with a clearly defined outcome [48]. Hence, models for such procedures will tend to be simple, serial graphs making them ideal for our initial HMCS work. Preliminary work on describing such procedures by hand supports this conclusion [49]. Finally, there is a large corpus of skilled users who are interested and willing to collaborate with us on this enterprise (see attached letters of support).

Specific surgical procedures that we consider throughout this proposal are:

Vein cannulation: the insertion of a needle or catheder into the lumen of a blood vessel. Retinal vein cannulation is an active area of medical research in which we done preliminary work [50].

Membrane peeling: the removal of a thin membrane over another structure. We have initial experience with retinal membrane peeling using a suction device. This operation is also sometimes performed using a forceps. This is particularly interesting as it is a simple, *repetitive* task.

Stapedotomy: an inner ear procedure where a small bone (the Stapes) is replaced by a prosthesis. We are currently engaged in limited user trials of steady-hand augmentation for two portions of the Stapedotomy procedure: 1) fenestration (making a small hole in footplate of the stapes bone) and 2) prosthesis placement [51].

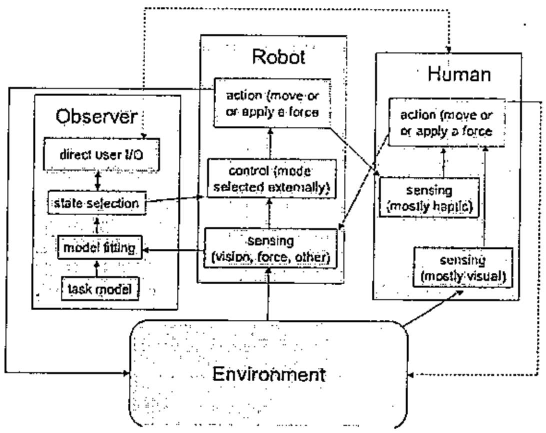
Anastomosis: suturing to join tissues. A specific instance is blood vessel anastomosis. Suturing is ubiquitous in surgery, and takes place at many physical scales, thus good human performance data is available for comparison and validation. At the same time, the procedure, while repetitive, is much more variable than membrane peeling and offers a wider variety of opportunities for human-machine cooperation. It is worth noting that joining a single 1mm blood vessel can easily consume 1/2 hour; successful reduction of this time through HMCS would have high impact on current surgical practice.

We will develop complete HMCS systems on two architectures: direct manipulation using variations on the JHU Steady-Hand Robot [14, 10], and indirect manipulation using the Steady-Hand Robot with a Phantom as a master input device. Multiple architectures will allow us to perform comparative tests to determine how architecture affects the *user's* perception of, and performance with, the system (see Section 2.3). Two architectures also broaden both the range of tasks we can explore and the set of questions we can examine. In particular, multiple target architectures will force us to develop our systems infrastructure in an architecturally neutral fashion, thus broadening the appeal and applicability of our results.

Finally, we intend to experiment with systems that play various roles within the described procedures. For example, we may have a robot that augments only one hand or both hands of the surgeon. In this case, there is a high premium on ensuring that the system has a natural "feel," and is highly interactive. There is also a tradeoff, in this case, between offering a relatively constant interface to the robot, versus changing the behavior of the system as the procedure progresses. Conversely, the robot might play the role of a "third hand" in which case safety and ability to anticipate the actions of the surgeon are at a premium, while constancy and reactiveness are less acute. These ideas are further elucidated in the Technical Approach and Research Plan, below.

2 Technical Approach

Figure 1 depicts the general structure of the human-machine collaborative systems we propose to investigate. Within this structure, there are two essential aspects to focus on. First, the behavior of the robot is governed



System schematic: a user primarily manipulates the environment through the robot, although unaided manipulation may take place in some settings (dashed line). The user is able to visually observe the tool and the surrounding environment. and directs the robot using force (or equivalent position) inputs. The robot has access to endpoint force data and/or targeted visual data. In some cases, additional information may be furnished by other sensors depending on the application (e.g pre-operative or intra-operative imaging). An independent observer has access to all available sensor data (including haptic feedback to the robot) and controls the mode the system is in. Optional direct interaction between the observer and the user is used to inform the user of the internal state of the system, and to acquire other discrete inputs (e.g. switches, pedals, or simple speech recognition).

Figure 1: An overall view of the system we propose to construct.

by a discretely changing set of control modes. These control modes use sensor signals from the environment *and* from the human partner to provides differ types of haptic (or other sensory) assistance. Second, the choice of control mode is made by an observer that is constantly estimating the current state of the manipulation task from the complete set of sensory signals, additional inputs from the human, and a prior task model.

Given this background, the fundamental design problem in HMCS is conceptually quite simple to state: *Design a system that, at any point in execution, chooses the sensor signals, control modes and/or user output that provide the most effective cooperative task performance.* In order to attack this problem, we consider three inter-related subproblems: 1) **Synthesis:** What systems tools are necessary to describe and develop an HMCS? 2) **Modeling:** Given sensor traces of a human performing a task, it is possible to a) segment the task into logical components; and b) measure the compatibility of a given HMCS structure to that sequence of components? 3) **Validation:** How can HMCS performance be measured or evaluated? By attacking these problems, our goal is to develop a "design science" for HMCS.

A key part of our approach is motivated by the following observation

> For the restricted set of micro-surgical problems described Section 1.2 and given sensor traces taken from a user while the robot is operating in a fixed, baseline compliant motion control mode, it is possible to segment tasks into discrete set of actions from sensor traces. Further, many of these actions are *task independent* and for each such action there is a relatively small number of appropriate performance enhancing control modes.

To make this point more concrete, consider rough procedural descriptions of two of our benchmark procedures:

Vein cannulation: 1) Site selection (constraint: site is on a blood vessel); 2) coarse motion to the selected site (constraint: needle should not touch surface); 3) alignment to the blood vessel at an appropriate grazing angle (constraint: needle tip should remain fixed); 4) motion along tool z axis to accomplish puncture (constraint: needle should not go through the opposite wall of the vessel).

Here, portions of the task that require judgment by the operator are the selection of the appropriate site, and the suitable range of motion to perform cannulation without puncturing the opposite wall of the vessel. In both cases, significant support can be given using simple vision tools to track and guide instruments, and the recognition of puncture in the force signature to perform back-stopping.

Anastomosis: A suitable repetition of 1) select a site for a suture (constraint: appropriate distance and sidedness from previous suture(s)); 2) move the needle to the site until in contact; 3) align the needle for puncture (constraint: needle tip remains fixed); 3) push needle through tissue until it emerges (constraint: apply forces along the needle path); 4) grasp needle; 5-8) repeat 1-4 for the opposite tissue wall (constraint: site is again appropriate in position and sidedness); 9) tie off.

Here, the portions of the task that require judgment by the operator include the selection of the site and detection of needle re-emergence. Again, simple visual tools and instrument guidance modes can provided significant support.

Similar analysis of other micro-surgical tasks suggests[1] that a relatively small family of action primitives is needed to describe them, including: a) motion toward a point in space, along a path, or relative to a surface; b) alignment relative to a surface; c) termination of motion by light (or near) contact, termination by a force signature, or termination by cessation of motion; and d) judiciously applied force. The augmentations that potentially apply are similarly bounded and include (previously discussed) virtual fixtures, force scaling, and various safety bounds on position or force.

If we put all of these ideas together, what we have said is that: 1) we want to describe tasks in terms of a (possibly non-deterministic) sequence of primitive actions, 2) each action has an associated performance enhancing augmentation, and 3) each action has an associated model that describes the expected sensor traces from a user when this action is being performed. We propose to relate all of these ideas through an appropriately descriptive *specification language* common to task modeling, system synthesis, and (ultimately) system validation. This specification would describe a task as a nominal sequence of actions with associated sensor signals governing that action, and an appropriate augmentation to invoke for that action. Thus, at one level, this specification is a "program" consisting of a sequence of control laws with associated termination conditions. At the same time, it also contains information about the appropriate sensory cues to use. Yet, since each action has an associated model, this specification also defines a *reference model* for sensor traces of human task performance. That is, this specification conveys

The Intent: From the specification, we know the human intent is, for example, to touch a particular point in space, where the target is obtained visually, with the ultimate goal of moving into contact, then to apply a specific type of force. Thus, we know both the objective of the manipulation, and the sensory information relevant to its execution.

A Performance Model: If we were to analyze force, vision, and position data of a human performing this activity in a baseline control mode, then we should see behavior consistent with a user attempting to move toward a visually defined target point, a characteristic force spike at the end of the motion, subsequent applied force along the needle, and so forth. In short, patterns of activity consistent with the specification.

A Validation Criterion: If we were to analyze the same data of a human performing this experiment *with the augmentation system active,* then we would expect to see behavior where the human inputs and the system control inputs are, roughly speaking, consonant with one another. If not, then the human is "fighting" the augmentation system, suggesting something about the specification is incorrect.

Means for Adaptation: The specification defines the broad structure of an activity. However, to define a virtual chamfer or force scaling, a programmer must specify a set of gains that are appropriate to the task. By segmenting data into locally consistent components, we can "fit" user data to models of expected performance for that episode and thereby potentially "tune" the augmentation system. As a result, the system should improve its performance over time. We note that this topic is the subject of a related project (see Section 6) and will not be addressed substantially here.

In summary, our approach to HMCS development can be viewed as an iterative activity of 1) data acquisition, task modeling, and task model verification; 2) system synthesis; 3) independent system validation. The primary aim of our research is to develop broadly applicable techniques and tools for this process; in essence to create a general "design science" for such systems. The remainder of this section outlines our specific approaches to each of these problems.

2.1 Task Specification and Systems Structure

A task can be viewed abstractly as a state graph, where each state corresponds to an action, and state transitions are typically caused by discrete, asynchronous events. Our goal is to develop a means of specifying

[1]We note that we also have preliminary, quantitative experimental data to support our hypothesis that actions can be modeled in a task independent manner (see Section 2.2).

these graphs that can serve as both a "program" for implementing an HMCS, and a "reference model" for sensor signals taken from the environment and operator. In the latter case, specialized algorithms will be used to "train" a system from acquired data, or to segment sensor data into the actions described in the specification (further discussed in Section 2.2).

If we first consider a specification as a "program," then, for the purposes of discussion, it is convenient to divide the overall structure into two components:

Continuous control and estimation (the action level): This includes passive and active guiding of the operator, as well as continuous observation of motion or force. This level is highly automated, is dependent on the robot system architecture, and is driven primarily by direct sensor inputs (both from the human and the environment) to the system as noted in Figure 1.

Hybrid systems representations (the task level): This level introduces the notion of sequencing through different "modes" of continuous control [52, 53]. For example, performing passive guiding until a signal terminates the operation, then going into a passive "observation" mode until assistance is again required. The discrete switching may be driven by the user or could be based on sensor inputs as noted in Figure 1. Also, this level of specification is architecture independent.

Focusing first on the action level, we can divide the associated control modes into *compliant control modes* that do not impose any sort of guidance or feedback on the user, *passive guidance modes*, *haptic enhancements*, and *active motion controls*. Compliant control modes form the baseline augmentation of the system. In particular, these modes are used for collect data for initial task modeling as described in Section 2.2. Passive guidance modes impose some constraint on user motion, but do not actively move the robot themselves. Examples include virtual fixtures (virtual walls, tubes, chamfers, and so forth), "snap to" augmentations, and so forth. Haptic enhancements include various types of force and/or position scaling.[2] Active motion controls include classic path following, including execution of a pre-taught path. It is worth noting that, in addition to robot control, some of these modes can also operate by producing visualization aids (e.g. overlaying force information onto a visual display).

In preliminary work, we have implemented and evaluated basic compliance [54], visual path-following fixtures [15] and force scaling [55]. One challenge is to now extend and generalize and these algorithms. That is, these control laws must generalize across sensing modalities—a virtual fixture might be defined by vision data, force, or position. They must be relatively complete: a virtual fixture might be designed to achieve motion to a point, along a line, or in a surface. Finally, they must be composable: we may wish to constrain motion to a path, and simultaneously implement force scaling *along* that path. A related challenge is to incorporate state change (sequencing) into the execution model in a safe and reliable manner.

We propose to adapt our our prior work on *time-invariant* specification of system behavior to create a framework for specifying task models. This work is based on the functional reactive programming (FRP) model [56, 57, 58, 59, 60, 61, 62] as extended to vision and robotics [63, 64]. In the FRP model, system behavior is specified as an equation on quantities that are implicitly time-varying. This programming methodology is fully featured—it provides for type-safe parameterization, the ability to pass information between execution states of the system, and so forth—and is fairly well understood. Thus, it provides a convenient substrate from which to explore language abstractions for HMCS. Furthermore, independent but related work in both the user interface community (e.g. [65]) and the robotics community (e.g. [66]) have confirmed the value of similar "dataflow-like" means of program specification. Other specific advantages of the FRP approach include: 1) a clear and concise combination of asynchronous (discrete) and synchronous (continuous) coordination and processing of data; 2) a "state-free" expression, making the interpretation of a specification transparent, 3) a very small language core; 4) strong typing, making it easier to write correct programs, 5) a convenient means of admitting external libraries by "lifting" them to time-varying data streams, and 6) implementations in C++ [67], Java [68], and Haskell [62]. In particular, the fact that the language is fully declarative means it is possible to retarget the language as a performance model rather than an executable structure.

[2]Note the availability of position scaling will depend on system architecture; it is not possible in direct manipulation.

To take the suturing example, we can start by writing two low-level specifications[3] for a velocity-based control system:

```
Forcescale(scale) == scale * (userforce - tipforce)
Pointfixture(scale,controlpt,target) == scale * (target - controlpt) + userforce
```

`Forcescale` defines a force guided motion (with scaling). `Pointfixture` defines a law that acts as a "spring" to move the user to a point. Note that `userforce` and `tipforce` are time varying quantities pre-defined by the robot interface and are therefore architecture dependent. We now add the following lines:

```
Approach(controlpt,target) == project(z-dir,Forcescale(k1nominal)) +
                              project(x-y-plane, Pointfixture(k2nominal,controlpt,target))
Touch(thresh) == norm(tipforce) > thresh
system == robot <<= Approach(vistrack(tooltip),vistrack(target)) until
                              Touch(thresh) then Stop
```

The first line combines our two low-level primitives by projecting and superimposing their outputs. The second describes a notion of "touching" something. The final line states that the robot is controlled by (receives data from) `MoveToward` until the `Touch` condition is triggered, at which point it holds station. Here we have introduced the `vistrack` function which defines two continuous streams of reference values obtained by visually tracking a target in the image sequence. The final result is essentially a two-state hybrid system where executing `system` would lead to the describe robot control policy.

Note that the second group of statements can be implemented to be *independent* of the underlying robot architecture, and indeed are at the level of actions (e.g. approach) and termination conditions (e.g. touch). Normally, a user would not define them, but rather would use them as primitives in a task specification. As a result, if we wish to construct a performance model from the equations, *these same primitives can be redefined to expand to modeling primitives rather than execution primitives.* That is, `Approach` would become a function that tested the associated data streams to see if they are consistent with an approach action to the given target. `Touch` would test whether a specific force peak signature existed in the data. In the final line, the following steps would occur: 1) two visual trackers would be required to acquire data for the `Approach` model, 2) in the equation expansion process, these data sources would be linked to the underlying modeling primitives, and 3) the final system would consist of the `Approach` and `Touch` models concatenated serially and followed by a quiescent state. The execution `system` would now acquire, segment, and possibly fit (up to any free parameters) the defined model to user data. A more general view on how specifications relate to human performance models is provided the next section.

To move from this simple example to real HMCS applications, we will need address a variety of issues. One of the most challenging is the integration of generic real-time vision. Clearly, it is not possible to discern, in the abstract, what the user is looking at when performing a task. One way around this problem is to create a skeleton task model *before data collection takes place.* The primary purpose of this skeleton is to identify the sensor traces to focus on during different task stages, and in particular to define targeted vision objectives. Another possibility is to provide an interface during training that lets the user select specific visual cues from a pre-specified palette. Once the specific visual cues have been identified, our previous work on visual tracking [69, 70, 71] suggests that we can achieve good performance without performing general-purpose scene interpretation or image segmentation. In cannulating a small blood vessel, for example, it is possible to provide a relatively simple vision operator that can lock onto and track a single vessel or vessel junction point. We would rely on the surgeon to select an initial target (if necessary) by use of a pointing device or simply by guiding the robot toward the vessel until the target is acquired. Our premise is that, although the individual vision primitives are somewhat specialized, it is nevertheless possible to develop an HMCS architecture that incorporates them into useful strategies in a general framework.

Other issues we anticipate addressing include: How do we map the current set of FRP language abstractions to model definition in a straightforward manner? In particular, the FRP model is Turing-complete—it is possible to implement general recursive functions, to dynamically create new graph structures, and so forth. Is this too general? Are there more focused language abstractions that better capture this domain? How does the parameterization of a specification interact with the task model? More generally, what do we

[3] We are roughly following the FRP syntax as it is rendered in C++ [67]; in particular, the == operator does not indicate traditional assignment, but rather represents the assignment of a name to a computation over time.

need to add to the language to express contextual information such as leaving certain parameters free in the model (e.g. for the purposes of adaptation), adding constraints to the values of variables, and so forth. Finally, in the context of the observer depicted in Figure 1, can we make the language *reflective?* That is, one of the possibilities for sequencing an HMCS is to use the task model to determine what the current state of manipulation or exploration is. How can this be naturally incorporated into the specification language and execution model?

2.2 Human-Machine Modeling

Data traces taken from the robot are a quantitative record of cooperative task execution. These traces constitute the data available to control the actions of the robot, and include both sensed environmental and human inputs. In particular, during the training phase, we may include extra system inputs (e.g. foot pedals) that effectively label when task transitions take place.

Given this data, we wish to answer the following questions:

1. How and to what degree can we apply uniform modeling techniques to describe the actions that people employ when performing goal-directed dexterous activities? In particular, to what extent is there uniformity across time, individuals and skill level.
2. Can we then identify common, context independent, sub-elements of such models that would correspond to action primitives? If so, what degrees of freedom do we need to allow in the models to effectively fit them across user populations?
3. Can we compose these models to form a task model just as we compose augmentation primitives to form a task-level augmentation? If so, can we effectively segment specific user data online given such a composition? Can such a model be used to detect ineffective or incorrect task models?
4. Are there situations where we can in fact "parse" user input data into the "vocabulary" of our specification language? That is, given a coarse sketch of a task, can we improve that description automatically from data, or perhaps select the appropriate augmentation structure (e.g. right or left-handed operation) online? .

The first question is now to elicit human performance models from data [72, 73, 74, 75, 76, 77]. Potential techniques for fitting such models to data include unsupervised clustering, e.g using kernel machines, variations on classical system modeling tools [78], heuristic estimation techniques specifically aimed at model identification, e.g. [79, 80], and techniques for training Hidden Markov Models (HMM) (the leading technology for speech recognition).

Of these, we prefer HMMs because of very successful prior work with HMMs by a wide community of Human-Machine Cooperation researchers including our own group (see sec 2.2.1 for review). Hidden Markov Models (HMMs) belong to a very broad class of statistical models called graphical models. Briefly, HMMs are a Markov random process which can occupy one of N states. A *hidden* Markov model, λ, has an initial state probability vector, Π, and a $N \times N$ state transition matrix, A. States are "observed" via a random variable drawn from a PDF specific to each state – the "state observation density," B_i. The probability of changing from one state to another at each discrete time sample is determined by A. An N state HMM therefore is described by

$$\lambda = \{\Pi, A, B_1, B_2, \dots B_N\}$$

The following properties of HMMs make them very attractive for modeling human manipulation and exploration:

- Broad applicability – HMMs can accommodate general, multi-variate statistics that change with time or with context (e.g. the state of manipulation).
- Well known and optimized algorithms have been developed to work with HMMs (see [81] for a comprehensive review). In particular, efficient algorithms exist to solve three canonical problems which we will refer to subsequently: **Problem 1:** Compute the probability of an observation sequence given an HMM; **Problem 2:** Compute the most likely state sequence from an observation sequence and an HMM (the Viterbi decoder); and **Problem 3:** Determine the parameters of an HMM from an observation sequence.

- HMMs can be numerically identified in a "black box" mode, but it is also possible to constrain the numerical HMM learning algorithm (the Baum-Welch algorithm) to reduce its search space and improve learning performance [73].
- HMMs can accommodate a range of determinism. An HMM can encode deterministic behavior which depends on fixed sensor thresholds or probabilistic behavior based on learned or taught probability density functions (PDFs).

Perhaps most importantly, promising initial results have been obtained in both telerobotics and surgery [73, 75, 82].

We can draw a specific relationship between the elements of the HMM formalism and the proposed library of assistance modes. As noted above, an HMCS can be thought of as a serialized composition[4] of actions. Each action has a starting condition, a manipulation objective (a termination condition), and a set of expected sensory inputs. The HMM for a given action would consists of several interconnected states, each with a model of the sensory data appropriate to that state (force, position, vision, or a combination thereof). It is worth noting that HMMs having nothing to say about how to determine the control outputs of the augmentation associated with an action. A closely related model, the partially observable Markov Decision Process (POMDP), which has been studied in the context of re-enforcement learning systems, has the potential to address these issues [83, 84].

As a task evolves, it goes through the specified series of actions and (hopefully) converges on the overall goal state. The same serial composition of HMMs leads to a so-called "lattice" of HMMs, just as words are composed from HMMs for individual phonemes [85]. Based on human performance and successful robotic performance, we have expected values, and perhaps probability density functions, for the duration the system stays in each mode, as well as models for the expected sensory inputs. Thus, the resultant HMM is statistical model for the expected inputs to the HMCS during a tasks, as well as the sequence of activities in the task.

In making these connections, we also see how information about the task can be built into the model. For example by setting $A_{ij} = 0$ for all $i \neg = j$ we can constrain the HMM to follow a series of steps in sequence (the "Simple Left to Right" (SLR) model in HMM terminology). The order is deterministic but the transition times remain stochastic. Constraining which state transitions cannot occur by setting their initial $A_{ij} = 0$ is one of the most powerful ways to build domain knowledge into the HMM because the Baum-Welch algorithm does not alter values in A which are initially zero (for an evaluation of this effect in manipulation models see [73]).

In some cases, it may be useful to develop HMM models for activities in multiple ways, and allow online model identification to determine the appropriate augmentation mode. A simple example is handedness: left- and right-handed surgeons tend to approach the same procedure rather differently. In this case, we would compose two HMMs, one for left-handed surgeons and one for right-handed ones, that would operate "in parallel." An appropriate analogy is the use of multiple HMMs to describe the variation in pronunciation of words.

We recently have performed initial work to test whether it is possible to segment tasks into task-independent action models [82] using HMM networks. In our experiment, several users repeatedly performed two procedures: an insertion task that resembles vessel cannulation, and a "painting" task that resembles membrane peeling. During the procedure, the users pressed a foot pedal to indicate their segmentation of the task into a specific set of task phases. Some of the task phases were common to both tasks and some were task specific. Motion and force data was also collected. This "labeled" data was used to train one 7-state SLR HMM for each task phase. No pre-processing or prior clustering of the data was performed.

We then were able to achieve the following results: 1) task segmentation accuracy approaching 90% correctness on a fully connected network (that is, an HMM containing models for all actions but without any task sequence knowledge); and 2) for common task phases, HMMs trained on one task could be used to segment the other task with little (less that 2%) loss in accuracy. The former suggests that HMMs are a viable approach to task models; the latter that generic HMM models of task elements may be possible.

[4]It is worth noting that most micro-manipulation procedures do in fact have a serial structure as this tends minimize the cognitive load on the operator or surgeon. Curiously, we have recently anecdotally observed that in some cases, adding augmentation to the procedure causes further serialization and simplification. This seems to be related to the fact that some "dynamic" portions of procedures (e.g. quickly sticking a needle into a vessel reduces the effect of tremor) can be made quasi-static with the addition of a robot assistant.

2.2.1 Relation to Prior Work on HMM Modeling

Among the most prominent members of the graphical models class (HMMs, artificial neural networks (ANNs), and Bayesian networks) HMMs have the clearest structural correspondence with sequential processes such as those considered in this proposal. Recurrent ANNs (RANNs) have been shown to be mathematically dual of HMMs and thus can be mapped back and forth at will [86, 87]. Nechyba and Xu [88] have compared HMMs to Bayesian classifiers, and found that HMMs performed much better at classifying user inputs to a driving simulator.

HMMs were extensively developed in the area of speech recognition during the 1970's and 80's [89, 90, 91, 81]. Hannaford and Lee [72] first applied Hidden Markov Models to sensor data from remote manipulation experiments. They found that the Viterbi decoder, informed by an HMM, could accurately segment very noisy sensor data and identify an assembly state sequence as performed by the human. More recent work [73] has shown that *expert HMMs*, where a prior model is used to structure the HMM training process, can effectively represent surgical procedures. Pook and Ballard [92] applied HMMs for recognition of human manipulation actions sensed by a multi-fingered glove. Xu, and his colleagues [93, 94, 95, 96] also used HMMs for human operator modeling. They employed standard HMM techniques for system identification (problem (3)), and pattern matching (problem (1)), for such applications as telerobotics, human driving behavior modeling [93] and symbolic human inputs such as gestures [95]. Gesture recognition with HMMs has also received increasing recent attention from the rehabilitation technology community [97]. McCarragher [98] reported the use of HMMs to analyze contact state information in automated assembly. Itabashi et al. [99] have recently used HMMs to identify a series of human operator impedance states during a manual peg-in-hole insertion.

The proposed work differs from that cited above in the following aspects:

1. Most of the research cited above uses HMMs only for the pattern matching problem (HMM problem (1)). This is a "black box" technique which precludes insight into the task structure and does not produce the powerful segmentation results of HMM problem (2).
2. To date, there has been no broad effort at developing and testing a significant, user independent "vocabulary" of HMMs that can be combined to describe a broad class of applications.
3. There will be strong interaction between the modeling and synthesis teams to determine how the models are described, constructed and how they are used in on-line verification and training of the system. In particular, a version of the specification language evaluation process will be developed to create HMMs. This version of the language will then be executable in training mode from previously acquired data, or in segmentation mode for fitting data.
4. Some of the research cited above has used pre-processors such as Vector Quantization to reduce the data dimensionality for the HMM, which reduces HMM complexity. This project will be the first to systematically assess the importance of this tradeoff for HMCS performance.

2.3 Validation

The goals of validation are to use measurements of system performance to substantiate the user models and to provide baseline data on the effect of the HMCS in task execution. For specific tasks, we will conduct human performance and perceptual experiments[5] to validate the HMCS design process. The exercise of developing and performing validation experiments will lead to insights into the association between task models, HMCS types, and validation metrics. For example, how do the appropriate measurements to acquire for performance validation relate to the fundamental type of augmentation or assistance that is being offered? It is possible to use human baseline data (without augmentation) to *predict* human performance with augmentation and thereby provide structure to the design of HMCS? Perhaps most importantly, is it possible to use online acquisition of baseline data to tune or adapt the system to a given user?

The problem of validation is difficult to attack generically, as it is heavily dependent on the underlying problem domain. There are, however, some guiding principles in human factors that should be addressed

[5] We note that two of the PIs (Okamura and Hannaford) have experience with human trials for human-computer interaction, and the proposal budget also includes provisions for a postdoctoral student in this area.

for any task [100]. We will consider three levels of system validation that roughly correspond to the three levels of system structure:

Psychophysics (Low-Level): Studies the ability of the HMCS to resolve intensive, spatial, and temporal variations in mechanical inputs and outputs.

Mappings (Mid-Level): Verifies that the HMCS exploits natural mappings to provide efficient communication between the human and the mechanized aspects of the system.

Performance (High-level): Compares the relative performance of two different HMCS systems.

The psychophysical and performance validations are straightforward because they are based on established techniques for analyzing motion, sensing and task execution. At these low and high levels of validation, the choice of appropriate metrics is the primary challenge. In contrast, the mappings validation is a new concept that requires special consideration. This middle level of validations tests whether the techniques used to sense human intent and apply augmentation are accurate and appropriate. In the following sections, we will examine these validation levels in detail.

2.3.1 Psychophysical (Low Level) and Performance (High Level) Validation

At the lowest level, HMCS are intended to improve performance by enhancing specific human sensory and motor capabilities. The field of psychophysics addresses the ability of humans to sense and resolve intensive, spatial and temporal variations in mechanical inputs to the skin (the "cutaneous" system) and to muscles, tendons and joints (the "kinesthetic" system). Typically, psychophysical experiments are used to measure unaugmented human abilities [101, 102]. However, we will use "system" psychophysical experiments in order to judge the ability to sense and resolve mechanical inputs (such as forces, positions, etc.) with the HMCS. For most cases, human-only psychophysical experiments will be unnecessary, as many results are already available in the literature [103].

One area of particular interest is the effect of changing system gains and other continuous parameters on performance. For example, consider puncturing the footplate during a stapedotomy (see Section 1.2). Preliminary tests suggest that force scaling improves the performance of surgical references [104]. At a psychophysical scale, we will want to determine whether the just noticeable difference (JND) in microsurgical tissue forces can be improved with the HMCS by scaling up sensed forces. Up to a point, this scaling will certainly help, as the original forces are too small to discriminate. However, if the forces become too large, one will find that the absolute JND is larger, according to Weber's Law [101]. A larger JND will decrease the user's sensitivity to small changes in force and thus defines a potential upper bound on force scaling coefficients. By experimenting with such basic psychophysical parameters, we will add to our knowledge of how a task execution model is affected by the HMCS and, more importantly, be able to bound some of the important parameters of this augmentation *based on its intended use.* If we were to ignore psychophysics and focus only higher-level performance evaluation, the task would appear as a "black box," making it difficult to analyze exactly *how* the HMCS is enhancing performance.

While classic psychophysical experiments are designed to test the limits of human sensing, high-level perceptual experiments will test the complete HMCS to verify its utility in improving task performance. To validate improvement, several comparisons can be made:

- Comparison of performance/perception with the HMCS versus unaugmented human performance.
- Comparison of performance with the HMCS versus autonomous robot performance.
- Observation of changes in performance/perception with the HMCS throughout the design cycle. Here, we can determine if performance is enhanced due to iterative improvements, where the steps of modeling, system design, and execution are repeated.

Metrics for these experiments will be determined during the initial human modeling stage of the work. The primary metrics in many human-computer interface systems are time for task completion and error rate [105]. For the example, or Stapedotomy we have done preliminary tests using measures such as applied force and accuracy of placement [51]. In [106, 54], time to completion and error were used to evaluate the performance of a two-state HMCS with isotropic, homogeneous control and foot-pedal state switching. Projected patient recovery time and user comfort are other possible metrics.

We will also create descriptions of global performance metrics for specific tasks. These global metrics will take into account many factors, such as execution time, position errors, force errors, etc. This analysis will help us improve comparisons between subjects and HMCS designs. For example, it is difficult to compare a subject that moves quickly but makes many mistakes to a subject who moves slowly but is very accurate. Fitts [107] defined a very robust model of human psychomotor behavior, but his approach is limited to modeling rapid, aimed, one-dimensional movements.[6] In addition, global performance metrics will aid and be aided by task modeling. An optimal task outcome will be the result of a series of actions that have parameters that can serve as performance metrics.

2.3.2 Mappings Validation

A major goal of this work is to exploit natural mappings so that users can interact with the HMCS efficiently. Validation will ensure that the user can easily observe and react to the following relationships:

- Between intentions and possible action. The user wishes to achieve a particular result as the consequence of sequence of actions; he or she must be aware of which immediate actions are available towards that end. For example, the user must be aware of the constraints and/or sensory enhancement given by the currently active augmentation relative to the current action being performed.
- Between actions and their effects on the system. The consequences of immediate actions will change not only the state of the task (closer or further away from the desired result), but also the state of the HMCS, which affects which subsequent actions are allowed.
- Between the actual system state and what is perceived by sight, sound, or feel. The user should be able to understand the current HMCS state using clear sensory feedback.

These mappings are the basis of what has been called "response compatibility" within the fields of human factors and ergonomics [100]. In spatial compatibility, subjects will perform faster and more accurately when they are allowed to respond in relation to classifications that make sense [108]. For example, subjects are much more adept at pushing a left key in response to a left stimulus, and a right key in response to a right stimulus, rather than mixing left and right [109].[7] Certain kinds of HMCS, particularly those using direct manipulation, are particularly suited to natural mappings. When teleoperated systems are used, care must be taken to ensure that optimal mappings are used, given various system constraints. When utilizing sensory substitution, one must verify that proper training is applied and/or the substitution is natural. Similarly, when virtual fixtures or other constraints are applied, the user may wish to control or be aware of changes in mapping.

Validation of response compatibility can be performed through a combination of objective and subjective experiments. In objective tests, error rate, execution time, and other metrics can be measured and compared for different mappings. In particular, we plan to experiment with developing HMM models for "nominal" user performance with augmentation modes, and to use data compatibility (HMM Problem (1)) as an objective measure of response compatibility. Subjective user feedback during task execution with an HMCS can also be accomplished through real-time queries. These mappings will not always be observable due to lack of user recognition of his or her own intentions or lack of time for user feedback during task execution.

Consider the example of suturing as described in Section 2. The fact that this task has multiple phases requires that the system recognize many possible phase transitions. We must first validate that the user's intent is correctly identified at each phase. This is accomplished by comparing user-identified transitions with sensed transitions. Second, the change in augmentation, which corresponds to a change in mapping of human inputs to system outputs, is validated. The user must be comfortable with, and possibly even expect, the new augmentations after a phase transition. In addition to using the HMM data compatibility to measure response compatibility, we can also observe the user's input immediately after transition. Is the user "fighting" augmentation? Are there sharp, undesirable discontinuities in motion or force? Such evidence of incompatibility will provide guidelines for improving human intent sensing, the expected order of phases, and individual phase augmentations.

[6] Within the scope of this work, we will not seek to create general performance models, but task specific models based on desired task outcomes.

[7] Through lengthy training, the difference in performance between spatially compatible and incompatible stimulus-response pairs can be minimized.

3 Organization and Research Plan

We will organize our activities into three thrusts: system development, modeling, and validation. In overview, our development will first focus on creating complete systems for "puncture" tasks, examining and exploiting the commonalities of those tasks for single-handed augmentation. In doing so, we hope to sufficiently understanding modeling and validation to the point that, by the end of year 3, our modeling techniques can *predict* the relative performance of a two qualitatively different HMCS specifications. Subsequent work will extend this ideas to 2-handed augmentation of repetitive tasks using suturing as an example, and, time permitting, on to cooperative execution where the robot plays the role of a "third hand." It is important to note that the basic robot infrastructure and some preliminary software tools are already in place, so we expect initial progress to be quite rapid.

The following plan gives a time line for individual thrust developments, and also illustrates how our thrusts will collaborate to achieve the goals set out in this proposal. We defer a discussion of personnel deployment for the project to Section 6.

Year 1: The systems group will begin development of the specification language, the underlying motion control primitives, and the related sensing and systems infrastructure. The specification language (as described in Section 2.1) will be implemented for our two robot architectures ("steady hand" and conventional teleoperation). In order to develop a comprehensive language, we will consider motion primitives for various tools, such as needles (translational and rotational motion) and forceps/scissors (grasping), although we will initially emphasize primitives pertinent to single hand puncture tasks such as cannulation, fenestration (a portion of Stapedotomy), and needle insertion. Initial system implementation efforts will focus on equipping our experimental workstation with a full suite of sensors, including stereo vision, tool handle force, vibration, etc., together with robust manual guiding modes, needed for measurement of human performance. From this base, we will begin developing higher-level primitives from our specification language.

Work will begin on modeling human baseline performance with simple compliant augmentation. Vein cannulation and fenestration will be the sample tasks. Our first goal will be collect a sufficiently large data corpus to perform statistically meaningful tests of data modeling and task segmentation. To this end, a selected from a group of JHU microsurgical fellows of varying skill levels, will perform several cycles of these tasks (after a suitable training period) while we record stereo video together with force, torque, and contact information. We will then test the following questions: can we train a common set of actions across the entire group and task corpus and achieve effective (e.g. $> 95\%$) segmentation? If not, what are the dominant factors that make segmentation difficult? Given these factors, can we discover data pre-processing or modeling methods that achieve our segmentation goals, or can we logically subdivide data (e.g. by experience) to achieve our goals?

The validation group will develop protocols for testing performance. In particular, we will determine which psychophysical parameters are important when augmenting individual actions and begin to develop methods for creating a "global" performance metric for puncture tasks. Comparative testing of direct and teleoperated performance augmentation will be done. We will also seek to identify information such as training rate that can be used in design of future studies.

Year 2: The primary systems goal in this year will be demonstration of the ability to describe and execute complete augmentation task sequences for puncture tasks. This will require incorporation of results of validation and modeling started in Year 1 both for "tuning" of specific parameters required by motion primitives and for detecting simple transitions between primitives. For example, if a virtual chamfer is being used to assist the surgeon in guiding a needle during a cannulation task, the system should be able to use a combination of computer vision and analysis of the surgeon's control inputs to determine when to narrow or widen the chamfer, adjust the desired target point, or terminate the action. This information should then flow appropriately to other primitives within the task specification.

The effectiveness of these augmentation strategies and of the techniques explored for adapting them will be evaluated by the validation group using the performance metrics developed in Year 1. Refinement of these metrics will continue in Year 2 (and throughout the entire project) based on additional controlled studies.

The modeling group will continue to refine and expand methods for segmenting data. During this year, we plan to bring a second robot online, and thus we can begin to acquire data on the suturing task. The models and techniques developed for puncture will be tested against this data, with the same protocol of questions as in year 1. We will also begin to acquire a data corpus from human-machine systems in operation,

again using our established protocols. Comparative testing of direct and teleoperated augmentation will be performed. Particular focus will be given to the efficacy of position scaling (teleoperated system) vs. gain scheduling (direct system) for fine-scale motion.

Year 3: The primary goals for this year will be 1) rigorous evaluation and improvement of the strategies demonstrated in Year 2 for cannulation and fenestration; 2) demonstration of the extensibility of the basic system to additional tasks; and 3) significant extension of the ability of the system to recognize and adapt to task transitions. We expect that suturing tasks will be chosen, although we will carefully consider other alternatives as well. For suturing, we will follow the basic method developed earlier for punctures. Many of the motion primitives (e.g., chamfers) developed for punctures should be readily adapted, but we will need to develop more sophisticated primitives combining force, impedance, visual, and geometric information as well (e.g., for tensioning sutures or for retraction). Also, during this year we will augment our workstation with a second manipulator and enhanced sensing capabilities for the study of two handed tasks.

The modeling group will develop online, real-time monitoring of task performance and task segmentation using the corpus of baseline data acquired from the HMCS for puncture tasks. The data corpus from the existing HMCS will also be modeled, using the same methodology and techniques as for the baseline case. The principle goal will be to develop models for actions *while augmentation is active*. These models will be in turn used in real-time online segmentation of a task while it is being performed.

Data will also be acquired by the validation group to perform system level comparisons. By the end of this year, we will be able to answer the following questions: 1) Given two systems A and B, is A better or worse than B, and 2) Given that A is *predicted* to be better than B by our models, is A better than B in a statistically significant way.

Year 4: Our primary goals during this year will be 1) demonstration and evaluation of an augmented two handed task such as suturing; and 2) using online segmentation to develop a robot that works side-by-side with a human to provide a "third hand" for a task (e.g., to hold a vessel while a surgeon inserts a suture). If we have not done so earlier, we will also identify and begin preliminary evaluation of the use of our system in a non-surgical application such as MEMS assembly.

As our underlying technology matures, modeling and validation will shift to the operation and improvement of an HMCS. In our sample tasks, we will observe human performance of a task *with* the system, and apply our modeling techniques to the result. We will do this for both system architectures. Based on the necessary user input, user feedback, sensor input, and system output for a given task, we will develop an understanding for which types of systems (as shown in Table 1) are appropriate for different tasks.

Year 5: The primary goal in this final year will be demonstration of a system that works both side-by-side and cooperatively with a human in the performance of a complex task. At this point, we expect to augment our workstation with a third manipulator. For suturing, a typical scenario might have the robot autonomously use manipulators to position the ends of two vessels while the surgeon controls a third to insert a needle using the augmentation primitives developed in earlier years.

4 Impact

Specific Goals: In our preliminary work on the steady-hand system and HMM analysis of surgical skills, it is already clear that HMCS have huge potential in the area of surgery [12, 11, 110]. We believe this preliminary evidence suggests that a more capable robotic assistant as we have outlined could have a commensurately larger impact. A related, medium term application for this technology can be in medical skills training and certification. This may be especially relevant to the emerging area of robotic assisted surgery, now in clinical trials by companies like Intuitive Surgical and Computer Motion. These systems will be an ideal entry point since they provide the complete hardware environment necessary for HMCS. We also believe the general framework we propose will apply to other aspects of robot assisted manipulation, e.g. space exploration, undersea construction, or precision assembly systems (such as in photonics).

Education Our vision is for HMCS to impact the development of revolutionary new educational tools. It will be possible to analyze expert data in a physical task such as surgery, calligraphy, or precision assembly, and use the HMCS idea to let beginners learn "what it feels like" through demonstration (passive watching), "hands on guidance" (via force feedback), and high level supervision [111, 112]. Again, preliminary evidence

in the surgical domain suggests that expert knowledge includes sequencing, timing, forces, torques, and speed of motion that the HMCS can replay, constrain, or monitor while the student interacts with the task.

This work will further impact education in two ways. First, undergraduate and graduate students will be involved in the research. (The proposal budget accounts for student stipends and tuition.) The infrastructure of the Engineering Research Center for Computer-Integrated Surgical Systems will assist in recruitment and coordination of NSF REU (Research Experience for Undergraduates) Scholars from Johns Hopkins and other schools. In addition, NSF RET (Research Experience for Teachers) Scholars will be invited to be a part of this project each summer. The PIs have had successful experiences in working with these Scholars in the past. Second, students working on the project from each school (The Johns Hopkins University or the University of Washington) will take short visits to work in the laboratory at the other school. Student exchange will promote cooperative learning and facilitate interaction between the two groups.

Broader Impact We contend that HMCS will have a profound, direct impact on information technology by allowing computational systems to assist humans in physical interaction with real environments. One possible example of this is is rehabilitation. Rehab robotics places humans and robots in the same environment and asks the robot to make up for a human disability or even perform physical therapy [113]. Suppose, for example, that a stroke victim has to re-learn how to tie a shoe. An HMCS that has been trained to aid in that task would allow the patient to practice with a trained "helper." Although many real-world factors make it difficult to apply technology to rehab, when the significant issues of cost, safety, and user friendliness are solved, HMCS ideas could play a central role in making the human-robot interactions effective.

5 Results of Prior NSF Support

Gregory D. Hager has been a PI or Co-PI on 7 NSF awards in the last five years (5 research grants, a CISE grant for postdoctoral research, and one grant to support a workshop). The most closely related to this grant is "Scale-Invariant Skill Augmentation for Cooperative Human-Machine Micromanipulation Systems" (IIS-0099770) for $380,000 over three years (Hager, Okamura, Taylor) began in September 2001. This research has resulted in three conference publications [15, 114, 82]. It is currently supporting one graduate student (for Okamura) and will eventually support 2. This work complements but does not overlap with the current proposal as described in the management section.

Allison M. Okamura was the recipient of an NSF Graduate Fellowship at Stanford University, where she studied dexterous manipulation with robotic fingers and the development of reality-based models for vibration feedback in haptic virtual environments. She also developed haptic exploration with robotic fingers at the Mechanical Engineering Laboratory in Tsukuba, Japan under an NSF Dissertation Enhancement Award. These awards resulted in eight refereed conference papers [115, 116, 117, 118, 119, 120, 121, 19] and a Ph.D. thesis [122]. At The Johns Hopkins University, support from the NSF Engineering Research Center for Computer Integrated Surgical Systems and Technology (EEC 9731478) has resulted in two submitted conference papers [123, 124] and a supplement entitled "PER/Tissue Force-Deformation Studies and Brachytherapy" (P980139N: $100,000 over one year, starting September 2001).

Russell Taylor was PI of NSF Award IIS9001684, "Cooperative Steady Hand Augmentation of Human Skills in Micromanipulation Tasks" (Taylor, Jensen, Whitcomb). The principal technical results so far are summarized in the body of the proposal. So far, 1 journal article [125] and 5 refereed conference papers [126, 127, 128, 106, 129] have resulted. Further infrastructure support has been provided under NSF Cooperative Agreement EEC 9731478, "Engineering Research Center for Computer-Integrated Surgical Systems and Technology." This infrastructure includes the development of the robot system itself, computational support architecture, and ongoing research on visual tracking, optical and other sensing. This work will provide sensing and manipulation capabilities for the proposed research. The proposed research will build on these capabilities by developing the ability to describe, execute, and train complex, sensor-based HMCS.

6 Management Plan

Coordination of Research: The research in this proposal has been organized into three parallel research thrusts. Professor Hager, as PI, will be responsible for coordinating activities between these thrusts. The thrusts are:

Systems: This thrust is led by Profs. Hager and Taylor. Additional personnel in this thrust include one to two graduate students and one engineer or engineer/postdoc. As noted below, this thrust will collaborate with other systems-related work on related research projects within the broader context of the Center for Computer-Integrated Surgical Systems and Technology.

Human-Machine Modeling: The leader of this thrust is Prof. Hannaford. Additional personnel in this thrust include Prof. Hager, Dr. Rosen (a research scientist at University of Washington), a graduate student at UW, and a graduate student at JHU.

Validation: The leader of this thrust is Prof. Okamura. Other personnel include Dr. Hannaford, a postdoctoral scholar, and two graduate students.

While we have divided the research into thrusts, in fact all of the PI's are broadly qualified and will participate in all aspects of the project. Furthermore, we expect a rather fluid evolution of personnel as research proceeds. In particular, as detailed in our research plan, there will be more emphasis on systems and human-machine modeling, while in later years validation will play a much larger role.

We plan to exchange students on a fairly regular basis as a means of ensuring the both groups are operating within a common environment. Early in the research, a team from Johns Hopkins will visit UW to install MRC, the core robotics library developed at JHU. Later visits will be made to install and test software developed for systems specification and control. Likewise, a team from UW will visit to plan user trials and ensure that a common modeling environment is shared by both teams. Further visits will proceed on an (approximately) bi-annual basis, with extended visits by students over the summer.

Coordination with Other Research This research grant leverages three other active projects. The first is the Johns Hopkins Center for Computer-Integrated Surgical Systems (CISST) led by Prof. Taylor. The CISST ERC has broad research thrusts: "Surgical Assistants," led by Prof. Hager, and "Surgical CAD/CAM." The Surgical Assistant work within the CISST ERC is primarily aimed at developing and testing applications of robotics to microsurgery. Thus, CISST plays an essential role by providing a conduit to practicing surgeons (see attached letters) and surgical residents. It will also provide some basic engineering support (e.g. by supporting the MRC library and the Steady-Hand robot software). In short, much of the basic technology needed to attack microsurgical problems will come from CISST, and much of the validation work will be performed in collaboration with it.

The second related project is a recent NSF Robotics and Human Augmentation Systems award, "Scale-Invariant Skill Augmentation for Cooperative Human-Machine Micromanipulation Systems" has been recently funded through the Robotics and Human Augmentation Program. This award is focused on the related question of whether macro-scale augmentation can be mapped to micro-scale augmentation. As such, it will provide additional support for system development and broaden the scope of activity in this area by one graduate student. That grant also focuses on the problem of performance adaptation which is complementary to the work proposed in this grant (also one graduate student).

Finally, the UW group has recently been recommended for funding of a 4 year project, "MiniRobot design for military telesurgery in the battelfield: breaking the size barrier for surgical manipulators," (Prop. # 012296) from the 2001 DOD Peer Reviewed Medical Research Program (PRMRP/CDMRP). This project will investigate mechanism design and force feedback control issues through the development of a research prototype dual-handed surgical telerobot. When completed, this prototype will be an ideal platform for validation studies of HMCS.

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EXHIBIT N

UNITED STATES DISTRICT COURT

DISTRICT OF NEW JERSEY

RAJESH KUMAR,)
Plaintiff,)
vs.) No. 2:12-cv-06870-KSH-CLW
THE INSTITUTE OF ELECTRICAL)
AND ELECTRONICS ENGINEERS,)
INC.,)
Defendant.)

Deposition Upon Oral Examination of

BLAKE HANNAFORD, Ph.D.

9:53 a.m.

Tuesday, December 17, 2013

1201 Third Avenue, Suite 2200

Seattle, Washington

REPORTED BY: Keri A. Aspelund, RPR, CCR No. 2661

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E-X-H-I-B-I-T I-N-D-E-X

Continued ...

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E-X-A-M-I-N-A-T-I-O-N

(Note: * Denotes phonetic spelling.)

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Seattle, Washington; Tuesday, December 17, 2013
9:53 a.m.

BLAKE HANNAFORD: Witness herein, having been
duly sworn, testified as follows:
E-X-A-M-I-N-A-T-I-O-N
BY MR. STAHL:
Q. Mr. Hannaford, good morning, my name is Eric Stahl, we met earlier today.
A. Good morning.
Q. Good morning.
Could you state your full name and address for the record.
A. Sure, Blake Hannaford, 5634-12th Avenue Northeast, Seattle, Washington 98105.
Q. Okay. And you're here today as an expert witness on behalf of the defendant in this case, which I'll refer to as IEEE; is that correct?
A. That's correct.
Q. Have you ever had your deposition taken before?
A. Yes.
Q. And how many times?
A. I think three times.
Q. Okay. Were those all in connection with expert testimony?

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A. One time -- yes, except for once in which there was an issue at the university that I was peripherally involved in.
Q. What kind of issue?
A. There were some royalties from patents, and an inventor was suing the university, and I had received royalties from a completely separate invention, and they wanted to know if the university was applying their policies consistently, I think.
Q. Okay. And the two expert depositions you've given, what were those?
A. There was one in a matter of Nintendo versus a small company in patent litigation. I was on behalf of Nintendo, who was the defendant. Another one was a case of Medtronic versus an inventor who was accusing Medtronic of patent infringement.
Q. So, both patent cases?
A. Yes.
Q. Have you ever been and an expert in a copyright case before?
A. No.
Q. So, you've had your deposition taken before, so you understand the court reporter is taking a verbatim transcript?
A. Yes, I do.

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Q. So, you understand it's important that we try not to talk over each other; I'll let you finish your answers, you let me finish my questions?
A. Yes.
Q. And it's also important that you answer verbally as opposed to nodding or saying uh-huh.
A. Understood.
Q. Okay. And you understand you've taken an oath to answer all my questions today under penalty of perjury?
A. I do.
Q. If I ask any question during the course of the deposition that isn't clear to you, let me know, and we'll figure out a way to ask a better question.
A. I will.
Q. Okay. Have you ever testified at trial either as an expert or as a witness?
A. I did at a hearing of the International Trade Commission, which is technically not a trial, I think, but it seems like a trial.
Q. It's a proceeding?
A. Yes.
Q. What sort of matter was that?
A. That was the Nintendo patent matter.
Q. Okay. Have you ever been a party to litigation yourself?

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A. No.
Q. What do you do professionally?
A. I'm a professor of electrical engineering at the University of Washington.
Q. Your CV, which we'll look at at some point today, says you're also a professor of surgery?
A. Yeah, I have adjunct appointments in actually mechanical engineering, bioengineering, and surgery.
Q. But your academic background is in electrical engineering?
A. That's right, I'm not an M.D.
Q. Okay, no medical training?
A. No.
Q. So, how did you become --
A. Well, almost no medical training.
Q. Okay, I was going to --
A. I took one course with medical students on neuroanatomy.
Q. Okay. So, how did you become a professor of surgery?
A. I've been working since the early '90s on research with surgeons at our medical school, and so to recognize that collaboration, I'm an adjunct professor in the surgery department.
Q. Okay. Do you teach medical students?

A. Yes.
Q. Where?
A. Page 25, in the middle roughly.
Q. The "Hidden Markov Models" --
A. Yes, "Subcontract on NSF ITR award to Johns Hopkins University."
Q. Were you a subcontractor on that grant?
A. Yes.
Q. What does that mean?
A. It means the NSF awards a grant to Hopkins, and then Hopkins wards a subcontract to the University of Washington for my part of it.
Q. What does the amount listed here signify? It says 85k.
A. That's the amount of money we got at the University of Washington.
Q. The dates don't quite match up. The grant we looked at earlier started I thought in 2002, this says your work started in April of 2001?
A. I can't explain that. It may be just an error in -- it's probably an error in my CV, because you showed me an NSF printout of the official award notices.
Q. What here indicates to you that this subcontract is the same as the NSF grant?
A. That it's an ITR award to Johns Hopkins

University. It's the only one that I know of.
Q. Okay. On page 32, the last page of the exhibit, lists your consulting engagements; are you with me?
A. (Nods head.)
Q. Yes?
A. I'm sorry, the question?
Q. Are you on page 32?
A. I'm on page 32.
Q. Okay, is this a full list of all of your expert litigation engagements?
MR. EWING: Objection to form.
A. To the best of my knowledge, it is.
Q. Have you been retained as an expert in the last four years in any lawsuit other than what's listed here?
A. In the last four years? I don't think so.
Q. Your fees in this matter, you're charging $500 an hour?
A. That's correct.
Q. Is that your usual rate for outside engagements?
A. Yes.
Q. How many hours have you worked on this engagement to date?
A. Between 20 and 30 is my guess.
Q. And that's up until today?
A. Not including today.

Q. The day is still young.
(Exhibit-10 marked.)
Q. I've had the court reporter mark the thesis as Exhibit-10, and I see you have it in front of you.
A. Yes.
Q. You read it as part of your engagement?
A. I did.
Q. Did you read all of it?
A. I think so.
Q. Okay. I don't need you to thumb through it yet, we're going to refer to it later, but let's go back to your report, and in the summary, in paragraph 2, you say that one of your opinions in this case is that the thesis and notably the task graph depicted in Figure 5.13, is not original to Dr. Kumar and consists of other -- I'm sorry, consists of common scientific concepts, the necessary steps of a surgical procedure, and other material found in scientific literature published before Dr. Kumar's thesis. Do you see that?
A. Actually, I --
Q. Did I miss --
A. -- disagree with your quotation of my paragraph.
Q. Okay. Did I read something incorrect?
A. Yes.
Q. Okay. You said the thesis is not original to

Dr. Kumar and consists of commonplace scientific concepts, the necessary steps of a surgical procedure, and other material found in scientific --
A. I'm not seeing what you're reading.
MR. EWING: Where is thesis is not original?
Q. Well, I didn't read the full title of the thesis.
A. No.
MR. EWING: No, it says "the material contained in the doctoral thesis authored by Dr. Kumar published in 2001 and entitled 'An Augmented Steady Hand System for Precise Micromanipulation' (the 'thesis') that is at issue in this proceeding, notably the task graph, is not original to Dr. Kumar."
MR. STAHL: Right.
MR. EWING: It doesn't say the entire thesis is not original.
MR. STAHL: No, I agree with that. If I misread that, I apologize, and I thought I had started with "notably the task graph."
Q. But in any case, do you see paragraph 2, subpoint (1)?
A. I see subpoint (1) in paragraph 2, yes.
Q. When you say that the material referred to here is not original to Dr. Kumar, what do you mean by the term

point.
Q. Okay. Well, what's your general understanding?
A. Well, task level is higher than levels such as joint level. Joint level means rotation angles, velocities, and torques, characterizing a single motor inside a complex robot, but that's very low level. Task level is more referring to a function that a user would be interested in, like move until contact, or something like that.
Q. Let's go back to your report, which is Exhibit-9, and let me ask you to refer to paragraph 13 on page 4. And in paragraph 13 you refer to a Dr. Eugene de Juan. You say he previously published in the field of retinal vein occlusion, a condition that -- I'm sorry, a condition the Steady-Hand was designed to treat. Do you see that?
A. Yes.
Q. What is your basis for saying that the Steady-Hand was designed to treat retinal vein occlusion?
A. Well, I had knowledge of the Steady-Hand from visits to Hopkins, and so forth, and I think every time it was described to me, it was talked about in the context of the need to reduce surgeons tremor in trying to perform this retinal vein cannulation.
Q. Are you saying that the -- you're not saying

that the Steady-Hand was actually used to perform retinal vein cannulation on human patients?
A. Oh, no.
Q. You understand that it was a robot using retinal vein occlusion as an experimental platform essentially?
A. Yes.
Q. And in fact, at the time that Dr. de Juan wrote his article referred to in your footnote 2, 1999, the Steady-Hand robot was not being used to treat retinal vein occlusion in actual patients?
A. Oh, yes.
Q. Okay. And what is your understanding of Dr. de Juan's contribution to the Steady-Hand?
A. Well, he provides ophthalmological expertise in particular on this task.
Q. Okay. He's not a robotics expert as far as you know?
A. As far as I know, no.
Q. His article, referred to in your footnote 2, doesn't discuss a robotic-assisted --
A. No.
Q. -- procedure; is that correct?
A. That's correct.
Q. And it doesn't discuss robotic control software, for example?

A. Not that I recall.
Q. As far as you know, is any robotic device today being used to perform retinal vein cannulation?
A. Clinically?
Q. Yes.
A. No.
Q. Would you agree that Dr. Kumar's thesis is not describing a surgical procedure that had actually been performed clinically?
A. Yes.
Q. In fact, what it's describing is, again, a method for programming a robot to perform some of the tasks needed to do that procedure?
MR. EWING: Objection to form.
Q. Would you agree with that?
A. That and other things are described --
Q. Okay.
A. -- in the thesis.
Q. And the task graph, Figure 5.13 in particular, is describing a method for programming a robot to perform some of the tasks to do the surgery as an experiment?
MR. EWING: Objection to form.
Q. Would you agree with that?
MR. EWING: Same objection.
A. I think it describes a method, a series of steps

and a method of doing it, but on the face of the figure, for example, there's no robots present.
Q. But neither the article nor the thesis are describing a clinical surgical procedure; correct?
MR. EWING: Same objection.
Q. They're discussing a method for performing robotic-assisted surgery that has not -- was not at the time and still has not been performed in a clinical setting?
MR. EWING: Same objection.
Q. Do you agree?
MR. EWING: Same objection.
A. They have not been clinically performed. Either the article or the thesis work has not reached the clinic, to my knowledge.
Q. Okay. Turning back to your report, paragraph 15, I wanted to ask you about this first sentence where you say, and I'm picking up about halfway through, "the JHU Steady-Hand robot discussed in the Salisbury Report, and also described in Dr. Kumar's Thesis, was not created solely by Dr. Kumar." Do you see that?
A. Yes, I see it.
Q. Okay. Do you believe that Dr. Kumar is claiming in this case to have solely created the Steady-Hand robot?
A. No.

as opposed to reflecting the way a human would approach the task?
A. No, I disagree with that.
Q. Okay. Do you have any understanding as far as how retinal vein cannulation is used to introduce medication into the eye?
A. A little bit.
Q. You understand that one of the things that can be done in the course of that procedure is to introduce medical or drug therapy?
A. Yes.
Q. Okay. And that's not reflected in Figure 5.13?
A. That's correct.
Q. Okay. Returning to your report, in paragraph 20 you discuss two patents by Backes, B-A-C-K-E-S.
Let me know when you're there.
A. Yes. Sorry, I need to get to paragraph 20.
Q. Okay. These two patents by is it Backes -- did I say that right --
A. Backes.
Q. -- Backes, do they discuss task graphs in the context of medical robotics?
A. No.
Q. Would you agree they don't describe augmented Steady-Hand manipulation?

A. I would have to look at them again actually --
Q. Okay.
A. -- to answer that.
Q. Well, would you agree, as you sit here now, they're showing no task graph, and they're discussing robotic-assisted retinal vein cannulation in either of the two patents?
A. Wait, sorry, could you repeat that question?
Q. Neither of the references in your paragraph 20 to the Backes patents contains any task graph discussing robotic-assisted retinal vein cannulation?
A. I believe that's correct.
Q. In your paragraph 21, you refer in reference 6 to a paper by Hou, H-O-U. Does that paper involve robotics at all?
A. No, it does not.
Q. These examples that you're citing in your report as undercutting Dr. Kumar's claims of originality, the Hou paper, the Backes patents, and the others discussed in this section of your report, were any of them works that you were aware of before your engagement in this case?
A. Some of them, yes.
Q. Can you identify which ones?
A. Let's see, let me look at the -- well, I could just go through the footnotes.

Q. Sure.
A. I was aware of the Steady-Hand work, of course. I was aware of Cadeddu, Stoianovici -- Jeffrey, and Stoianovici, and Kavoussi's work.
Q. Can I ask you, as you're doing this, to identify it by number.
A. Yes, footnote number 3 I was aware of.
Q. Thank you.
A. I was a little bit aware of Backes's work. I knew him when I was at JPL.
I was not aware of number 6 until I found it for this paper.
Number 7, Ferrell and Sheridan is extremely famous. I've known about that since I was a graduate student.
The number 8, Simmons, et al., I was not aware of.
Same with number 9 or 10.
Number 11, I was not aware of.
Number 12, which is the one I've corrected, corrected earlier, that one I was aware of.
Q. Okay.
A. Number 13, possibly, not sure.
Obviously I was aware of 14 because I was an author of it.

And 15, no.
Q. So, 15 you were not aware of?
A. I was not aware of it.
Q. Okay.
A. And 16, no.
I think that's it.
Q. Well --
A. No, there's more.
Q. Why don't you stop at page 14.
A. Okay. You mean page 14?
Q. Yes, my question was only related to the citations in this section.
A. Okay.
Q. So, for the references that you were not previously aware of, how did you find them?
A. Searching on the Internet.
Q. Can you recall what search terms you used?
A. No.
Q. You said searching on the Internet?
A. Google Scholar.
Q. Okay. Any other source other than Google Scholar?
A. No.
Q. Okay, and did you do anything more complicated than just entering search terms into the Google Scholar

Seattle, Washington; Tuesday, December 17, 2013
1:00 p.m.

MR. STAHL: Mr. Ewing, you have the cite for reference 12?
MR. EWING: I do.
MR. STAHL: Would you read it into the record, please.
MR. EWING: Sure, it's McCarragher, Brenan J., and Haruhiko, Asada, those are the authors, and the title is "The discrete event modeling and trajectory planning of robotic assembly tasks," publication is Transactions-American Society of Mechanical Engineers Journal of Dynamic Systems, Measurement, and Control, 117, (1995):394.
MR. STAHL: Thank you.
E-X-A-M-I-N-A-T-I-O-N (resumed)
BY MR. STAHL:
Q. Professor Hannaford, we're going to continue working our way through Exhibit-9, which is your report.
A. Okay.
Q. And let me ask you to refer to paragraph 25.
A. I've got it.
Q. Okay. And in this paragraph 25, you refer to an earlier work by Dr. Kragic, who is one of the authors of

the article at issue in this case; correct?
A. I did.
Q. Okay. And you say that this earlier work of Dr. Kragic, which is cited in reference 10 of your report, "contains a strikingly similar task graph (Figure 2)." And is that the task graph on page 10 of your report?
A. Yes.
Q. And this task graph described in Kragic Figure 2 copied on page 10 of your report, that is a task graph showing the opening of a door?
A. Yes.
Q. Okay. Which is not obviously the same task as retinal vein cannulation or the task shown in Dr. Kumar's Figure 5.13?
A. It is a different task.
Q. Okay. But you describe the two task graphs as strikingly similar, and my question for you is, in what way are they strikingly similar?
A. All the states are represented by ellipses, they're connected with curved arrows, and they represent successive steps in doing the task.
Q. So, it's your opinion that two task graphs are strikingly similar if they both show the states as ellipses, if they both connect by curved arrows, and if they depict the successive steps in doing a task?

MR. EWING: Objection to form.
Q. That's what you just --
A. That's one way they can be strikingly similar, yes.
Q. Okay. By that definition, you would agree that Figure 1 of the Kragic/Hager article, the article at issue in this lawsuit, is strikingly similar to Dr. Kumar's Figure 5.13, would you not?
A. They're certainly similar.
Q. You use the phrase "strikingly similar." Is it fair to say that the two retinal vein cannulation task graphs are at least as strikingly similar to each other as Dr. Kumar's Figure 5.13 is to the figure on page 10 of your report?
A. I suppose so.
Q. Paragraph 28 of your report refers to a work by two authors, and I'm not even going to attempt to pronounce these names, but it's T-S-I-K-O-S, Tsikos, and the second name is B-A-J-C-Z-Y.
A. C-S-Y. Oh, that's a typo, it should be C-S-Y. The footnote is correct.
Q. Thank you.
A. That's my typo, yeah.
Q. Okay. And that article in any event is reference 13 in your report?

A. That's right.
(Exhibit-15 marked.)
Q. Okay, and the task graph you are referring to in paragraph 28 of your report -- actually, there's several, you say Figures 7 to 10 of the report have substantially similar notations to Dr. Kumar's Figure 5.13 Just to be clear, you're referring to the figures on the last few pages of Exhibit-15?
A. Yes, Figures 7 through 10.
Q. What are these figures showing?
A. These figures are showing a sequence of states and events that define the transitions between the states in a robotic task.
Q. In what way are Figures 7 through 10 of Exhibit-15, quote, substantially similar, close quote, to Dr. Kumar's Figure 5.13?
A. They have states inside geometric shapes, round geometric shapes, that are connected by arrows, and the arrows are labeled by events.
Q. Fair to say that under that definition, Dr. Kumar's Figure 5.13 and Figure 1 of the Kragic/Hager article are also substantially similar?
MR. EWING: Objection to form.
A. Yeah, I don't -- I don't want to -- I don't want to stick to a precise definition of substantially there,

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but they're similar.
(Exhibit-16 marked.)
Q. Would you consider the task graphs in Exhibit-16 to be substantially similar to each other?
MR. EWING: Objection to form. This is beyond the scope of his report.
Q. As you used the term substantially similar in your report, would you consider the task graph at the top of Exhibit-16 to be substantially similar to the task graph in the bottom half of Exhibit-16?
MR. EWING: Same objection.
A. I'd say they're similar.
Q. Would you say they're strikingly similar?
MR. EWING: Objection to form.
A. They're similar.
Q. Would you say they're at least as substantially similar to each other as the task graphs you are comparing in paragraphs 25 and 28 of your report?
MR. EWING: Objection to form.
A. No.
Q. Okay, why not?
A. Well, I guess I'm having trouble equating degrees of substantialness, let's say, which is what you're -- I think what you're asking me to do.
Q. Or degrees of similarity?

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A. Yeah. I mean, I see significant differences between these.
Q. Okay, would you agree they are at least as similar to each other -- let me rephrase that.
Would you agree the two task graphs shown in Exhibit-16 are at least as similar to each other as the task graphs that you say are similar in paragraph 25 and 28 of your report?
MR. EWING: Objection to form.
A. Well, what I say in like 28 is that, for example, Tsikos and Bajecsy's task graphs have similar notation, and these have similar but different notation. They have different number of states.
Q. Going back to your report, Exhibit-9, there's a figure on page 13, your Figure 3; what is this figure showing?
A. Okay, so this is a citation -- a figure from this citation by Fleury, and it's -- it describes a graph of actions for -- of states that a robotic activity can be in and transitions between the states.
Q. What task is being performed here? What is the context?
A. This is general for any task.
Q. Does Fleury report on any actual execution of this task graph?

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A. I don't recall.
Q. Take a look at paragraph 33 of your report, Exhibit-9.
A. I see it.
Q. Okay. I'm just going to read the first two sentences. "Apart from the absence of originality and the use of task graphs in Dr. Kumar's Thesis, the articulation of the various steps in the process of performing retinal vein cannulation depicted in Dr. Kumar's 5.13 is also not original to Dr. Kumar." And let me stop you there.
By your reference to the various steps in the process, you mean the various states within the ellipses, move to port, orient, insert, and so on?
A. Well, I meant the steps in the process, and I guess they are represented in those ellipses.
Q. Okay. And they're also referred to textually on page 71 and 72 of his thesis; correct?
And that's Exhibit-10, which you should still have nearby.
A. Sure, I see that on page 71.
Q. So, when you say the various steps, you mean positioning, reorienting, insertion, adjusting, approaching the site, contact, puncture, hold to deliver therapy, and retract the tool?
A. Yes.

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Q. Okay. You go on to say in paragraph 33 of your report, "As noted above, that procedure was described in published literature before the Thesis was published and the JHU Steady-Hand robotic device was developed at least in part with that procedure in mind."
You know, when you say that the procedure was described in published literature as noted above, you're referring to your reference 2 that we looked at earlier, is that right, the article by Dr. de Juan?
A. I believe that's what I'm referring to there, yes.
Q. Okay. And we looked at it previously, but I think you agreed, he does not -- other than using the word "puncture," he does not describe the procedure in the same terms that Dr. Kumar does in his thesis on page 70, or 71, or 72?
A. He does not describe as many steps, that's right.
Q. Okay. You go on to say in paragraph 33 of your report, "Further, in Section III of the article, Drs. Kragic and Hager describe the process of retinal vein cannulation, citing an ophthalmological publication," with a citation number 16 to an article by a Jeffrey Weiss. Do I have that right?
A. Yes.

Q. And the portion of the article that you're referring to, and this is Exhibit-3, is the paragraph at the bottom of the first column on 3193?
A. Yes, I see it.
Q. With the citation to their reference 7, which is the same Weiss article?
A. Yes.
Q. Okay. And Kragic and Hager write in this part of the article, "As an example, retinal vein cannulation involves positioning and orienting of a needle to the vicinity of the vein, inserting it when appropriate until contact is made. On contact, puncturing is performed, after which the needle can be safely withdrawn." And they cite the Weiss article for that proposition.
Have you read the Weiss article?
A. I don't remember.
Q. Did you check to see whether the Weiss article supports the proposition for which Hager and Kragic cite it?
MR. EWING: Objection to form.
A. I don't remember.
Q. Do you recall whether Weiss describes the steps of retinal vein cannulation in this manner, positioning and orienting, inserting, puncturing, withdrawal?
MR. EWING: Objection to form.

A. No.
Q. You don't recall?
A. That's right.
(Exhibit-17 marked.)
Q. Exhibit-17, that's the Weiss article; correct?
A. Yes.
Q. Can you point to any portion of that article, Exhibit-17, where the procedure of retinal vein cannulation is described in the way that Kragic and Hager describe it in their article?
MR. EWING: Objection to form.
A. Well, in looking at this, I think I probably haven't read it, and so I should -- I would need to read it to answer that question.
Q. Okay. If Weiss does not in fact use the terms or describe the procedure using the words positioning, orienting, inserting, and so forth, would that change your opinion that Dr. Kumar's articulation of the various steps in the retinal vein cannulation procedure is not original?
MR. EWING: Objection to form.
A. No.
Q. Why not?
A. Because I had other ways to know what the procedure was, some of which I have described -- all of which I've described before today.

Q. Okay. Do any of them break down the process of retinal vein cannulation into the tasks as articulated in Dr. Kumar's thesis?
A. Well, I think the way it's described to me -- the way it was described to me, again, long before this case, described those steps.
Q. Who described it to you that way?
A. Oh, probably Russ Taylor. I don't have a specific recollection on that, though.
Q. If the decomposition of retinal vein cannulation into the steps set out in Dr. Kumar's thesis on page 70, and 71, and 72 were in fact Dr. Kumar's own creation, would that change your opinion as to whether Figure 5.13 is original?
MR. EWING: Objection to form.
A. I don't know.
Q. Okay. If that task decomposition were in fact original or created by Dr. Kumar, would that change your opinion as to whether Kragic and Hager copied from the thesis?
MR. EWING: Objection to form.
A. Probably not.
Q. Why not?
A. Well, there are a lot of differences between their figure and Kumar's figure.

Q. Are you aware of any third example, other than the Kumar thesis and the Hager and Kragic article, that breaks down retinal vein cannulation into these steps? And I think I asked you that question previously with respect to task graphs, and just to be clear, I'm asking a more general question in terms of task graphs or text or any other format, are you aware of any articulation of retinal vein cannulation into the steps as broken down by Dr. Kumar?
MR. EWING: Objection to form.
A. Other than my general knowledge of it, no.
Q. You've never seen it expressed that way anywhere else other than in the thesis and in the article?
A. I think that's correct.
Q. Okay. In the Weiss article, Exhibit-17, he discusses infusion with a drug called TPA, I'm looking at page 2249, the first page, the last paragraph on the page; do you see that?
A. Yes.
Q. Do you think that if Hager and Kragic in their article were in fact relying on Weiss as opposed to Dr. Kumar's thesis to describe retinal vein cannulation, that they would have mentioned the fact that the procedure includes delivery of TPA or some other drug therapy?
MR. EWING: Objection to form.

and puncture directly to retract rather than directly to the error state; is that correct?
A. Well, the rather than is something else, but these are -- those are transitions that are present in 5.13 which are not present in Figure 1.
Q. And the rather than, as you just put it, is what you cite as paragraph -- or subparagraphs 3, 4, and 5 in paragraph 41?
A. Your words were -- "rather than" were your words, so I'm just saying those are features in 5.13 which are not present in Figure 1.
Q. Okay, and instead of a transition between insert and retract in the article, there are, as you note in paragraph 41, subpoint 3, 4, and 5, transitions directly from those three states to error?
A. Right. So, additional differences are the presence of those transitions that are in Figure 1 and are not in Figure 5.13.
Q. You say in paragraph 43 that another major difference between the two works is that Dr. Kumar describes the procedures shown in the task graph using his own coding language, while the article describes the procedures using XML language; why is the different programming language significant?
A. Well, you know, a creative aspect of Dr. Kumar's

thesis was developing his own language to describe those tasks, and Kragic and Hager don't use that language, instead they've used a widely standard language, and I'm not saying the widely standard is better than individual language, it's just different. So, it's XML, so they used a very different language.
Q. Is that any different from taking a copyrighted work, say a book, that's written in English, and expressing it in a different language, in French, and claiming it as your own?
A. I think actually in this case it is. There's differences between those two languages which are also explained in paragraph 43, in the second half of 43.
Q. Well, that was my next question, you say that they use different programming idioms?
A. Yes.
Q. Can you explain to me what that means?
A. The XML, the way they've used it in this -- in section V, for example, is declarative, which means that you write your program by sort of stating what the results should be, not the detailed steps of how to get there. And Kumar's language in Appendix A is procedural. So, it says do this, and then this, and then this, and the end result is kind of implicit, whereas its explicit in the XML description. So, actually, I think it would be very

difficult to translate the two.
Q. Well, you say that -- well, let me ask you, are what you're saying is that Dr. Kumar's language is more detailed than the programming idiom used by the article?
A. Not necessarily. They could yield -- yeah, not necessarily. They're just different.
Q. Well, you say that Dr. Kumar's code contains verbs, in quotes, and the XML version in the article does not; is that what makes it difficult to translate from one to the other?
A. Yes.
Q. Why is that?
A. Well, again, for example, looking at the XML in Kragic and Hager's paper, these samples are definitions of things like events. Let's go to the first one, you know, "element name - procedures." I'm looking at the right-hand column of page 3195 of Kragic and Hager's paper --
Q. I'm with you.
A. -- and at the top, this is defining the -- this is a schema that defines a language for specifying these transitions.
Q. And how is that different from Dr. Kumar's language?
A. Well, if we go to that appendix, he gives examples, like say on page 95, you know, action count, if

such-and-such is true, then error equals error plus one. So, there he's giving an actual recipe for implementing this method.
Q. You say in your report it would be difficult to translate from one language to the other, or cannot be easily translated back and forth; would a translation be possible?
A. I don't know.
Q. You're not saying in your report that it's impossible?
A. I would need time to really answer that question.
Q. Okay, I mean, let me try out kind of a noncode analogy. We talked earlier about a book written in English, I take that English language book, I translate it into French, I then take out all the verbs in the French version, which would therefore make it not very easily translatable back into English; is that what you're saying is happening here? Is that an apt analogy?
MR. EWING: Objection to form.
A. No.
Q. Okay, why?
A. Well, you just said that -- I can't remember which book is analogous to which document here, but you're sort of saying it was translated from one language to the

S-I-G-N-A-T-U-R-E

I declare under penalty of perjury under the laws of the State of Washington that I have read my within deposition, and the same is true and accurate, same and except for changes and/or corrections, if any, as indicated by me on the CHANGE SHEET flyleaf page hereof. Signed in..............., WA, on the........day of................, 2013.

....

BLAKE HANNAFORD, Ph.D.

Taken: Tuesday, December 17, 2013

Keri A. Aspelund

C-E-R-T-I-F-I-C-A-T-E

STATE OF WASHINGTON)
) ss.
COUNTY OF PIERCE)

I, the undersigned Registered Professional Reporter and Certified Court Reporter, hereby certify that the foregoing deposition upon oral examination was taken stenographically before me and transcribed under my direction;

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TAKEN: Tuesday, December 17, 2013

EXHIBIT O

Injection of Tissue Plasminogen Activator into a Branch Retinal Vein in Eyes with Central Retinal Vein Occlusion

Jeffrey N. Weiss, MD, Leon A. Bynoe, MD

Purpose: Central retinal vein occlusion (CRVO) often produces significant and permanent loss of vision in the affected eye. The purpose of this study was to determine if patients with vision loss secondary to CRVO treated with retinal vein cannulation and infusion of tissue plasminogen activator (t-PA) experienced recovery of visual acuity.

Design: Prospective, noncomparative, interventional case series.

Participants: Thirty eyes of 30 consecutive patients with CRVO underwent the procedure, but two were subsequently excluded. The remaining 28 eyes of 28 patients with CRVO for an average of 4.9 months before intervention (range, 0.25–30 months) and best-corrected visual acuity 20/63 or worse were included in the study.

Intervention: All patients underwent pars plana vitrectomy with cannulation and infusion of t-PA into a branch retinal vein.

Main Outcome Measures: Change in visual acuity and the development of complications such as vitreous hemorrhage and neovascular glaucoma were monitored.

Results: Twenty-two of 28 patients (79%) experienced at least one line of visual improvement during the follow-up period (average, 11.8 months; range, 3–24 months), and the same number had this level of improvement at the last follow-up examination. Fifteen patients (54%) gained 3 or more lines of acuity within 6 months after the procedure, and 14 (50%) had acuity at last follow-up at least 3 lines better than baseline acuity (average, 6.8 lines). Seven patients had postoperative vitreous hemorrhages ranging from 1 week to 11 months after the procedure; two cleared spontaneously. One patient had a postoperative retinal detachment from a peripheral retinal break that was repaired successfully with pneumatic retinopexy. No other serious intraoperative or early postoperative complications were noted.

Conclusions: Vitrectomy with retinal vein cannulation and infusion of t-PA is a relatively safe procedure that may improve vision in eyes with CRVO. *Ophthalmology 2001;108:2249–2257 © 2001 by the American Academy of Ophthalmology.*

Central retinal vein occlusion (CRVO) is a common retinovascular disorder caused by intraluminal venous thrombosis at the level of the lamina cribrosa.[1] No safe treatment exists that promotes the return of lost vision. Treatments that target the secondary effects of venous occlusion, such as grid laser photocoagulation for macular edema and prophylactic panretinal laser photocoagulation for nonperfused CRVO, were shown to be ineffective in improving visual acuity in the Central Vein Occlusion Study (CVOS).[2,3] Attempts to bypass venous obstruction in CRVO using laser chorioretinal anastomosis have been performed with limited success and significant complications.[4–6] The systemic administration of thrombolytic agents to treat CRVO was shown to have some benefit.[7–9] In Elman's study,[9] 42% of patients treated with a systemic intravenous injection of 100 mg of tissue plasminogen activator (t-PA) an average of 21 days after onset of vision loss recovered at least 3 lines of vision (average, 5.1 lines) within 6 months, a rate much higher than what is seen for this level of improvement as part of the natural history of CRVO.[2,10] However, this treatment has been associated with serious complications, including patient mortality.

The authors believed that t-PA applied directly to the thrombus in CRVO may be a safer way to administer the drug and to provide at least the same benefit as systemic administration. We have previously reported the successful cannulation of a retinal vessel with infusion of t-PA in a patient with CRVO that resulted in subjective improvement in vision and clinical evidence of clot lysis.[11] In seven subsequent cases there were no intraoperative complications, there was an overall improvement in retinal perfusion status, and there was either modest improvement or stabilization of vision in all but one case.[12] Refinements in instrumentation and technique were being made during the time that the initial eight cases were performed. In this

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From the Retina Associates of South Florida, Margate, Florida.

Dr. Weiss has applied for patent rights on this technology and has financial interests (P, I) in Micron Ophthalmic, Inc.

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Table 1. Patient and Central Retinal

Patient No.	Age (yrs)/ Gender	Eye	Medical History	Ocular History	Central Retinal Vein Occlusion Duration (mos)	Type*	Relative Afferent Pupillary Defect	Posterior Vitreous Detachment
Snellen acuity								
1	64 F	Left	Ht, TOB	Glc (0.9 cup)	5	I	−	−
2	66 M	Left	TOB		4	I	−	−
3	63 M	Left	DM, CABG, TOB	ASN, Amb, grid laser PRP	30	N	+	−
4	76 F	Left	CABG	CE/IOL, grid laser	4	I	+	−
5	78 F	Right	CABG	Laser CRA 6 weeks pre-op	2	N	+	−
6	49 M	Left	Idiopathic clotting disorder	ASN, PRP, RVO right eye	2	N (I)	+	−
7	69 M	Right	TOB		9	N	+	−
8	72 M	Left	Ht	ASN (NVG) laser CilAb, CRVO right eye	18	N	−	−
9	62 F	Left	TOB		5	M	−	−
10	71 M	Left	Ht, TOB, CABG, ↑ chol.	LPI for angle closure	1.5	M	+	−
11	67 M	Left		ASN, Glc, RVO right eye	3	N (I)	−	+
ETDRS acuity								
12	71 F	Right	DM, Ht, Renal CA	CE/IOL	4	N	+	−
13	49 F	Left	TOB		10	M	−	−
14	55 M	Left	TOB, COPD	ASN	5	N	−	+
15	84 M	Right	Ht, Prostate CA	Glc, PXF	0.75	I	−	+
16	79 F	Right	DM, CHF, COPD, Valve replacement + pacer	Grid laser	6	M	−	−
17	65 M	Left	Bilateral carotid occlusion, TOB	CE/IOL	2.5	M	−	−
18	90 F	Right	Ht, ↑ chol	CRVO left eye, Amb right eye, CE/IOL	0.5	I	−	+
19	56 M	Right	Ht, TOB	LASIK	2	I	+	−
20	73 M	Left	Ht		6	M	+	+
21	74 F	Left	DM, Ht, TOB		0.25	I	−	−
22	82 M	Right	Ht, CAD, (angioplasty)	ASN	6	N	−	+
23	88 F	Left		CE/IOL	3.5	M	−	+
24	36 M	Left			1	M	−	−
25	63 M	Right	CABG, TOB	ASN, Glc	1	N (I)	+	+
26	78 M	Right	CABG, Ht, TOB		1.5	I	−	+
27	80 F	Left	Ht		1	I	+	+
28	85 M	Right	CAD, Ht	CRVO left eye, CE/IOL	2	M	−	−

Amb = amblyopia; ASN = anterior segment neovascularization; CA = cancer; CABG = coronary bypass graft surgery; CAD = coronary artery disease; obstructive pulmonary disease; CRA = chorioretinal anastomosis; CRVO = central retinal vein occlusion; DM = diabetes mellitus; glc = glaucoma; NVG = neovascular glaucoma; PA = potential acuity; PRP = panretinal photocoagulation; PXF = pseudoexfoliation syndrome; RD = retinal

*Central Vein Occlusion Study categories: I, indeterminate perfusion; M, macular edema; N, nonperfused.[6] Type in parentheses indicates the masked

†Early = best visual acuity within 6 weeks after retinal vein tissue plasminogen activator injection.

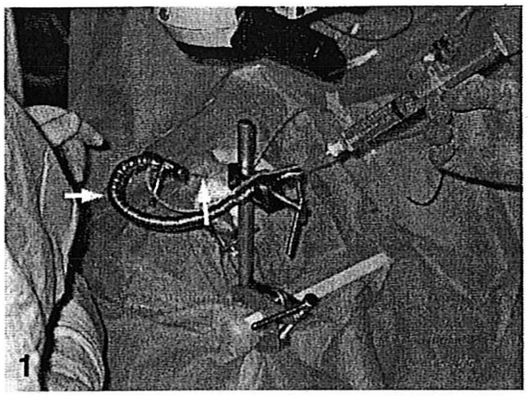
‡Best = best visual acuity after 6 weeks but within 6 months after the procedure.

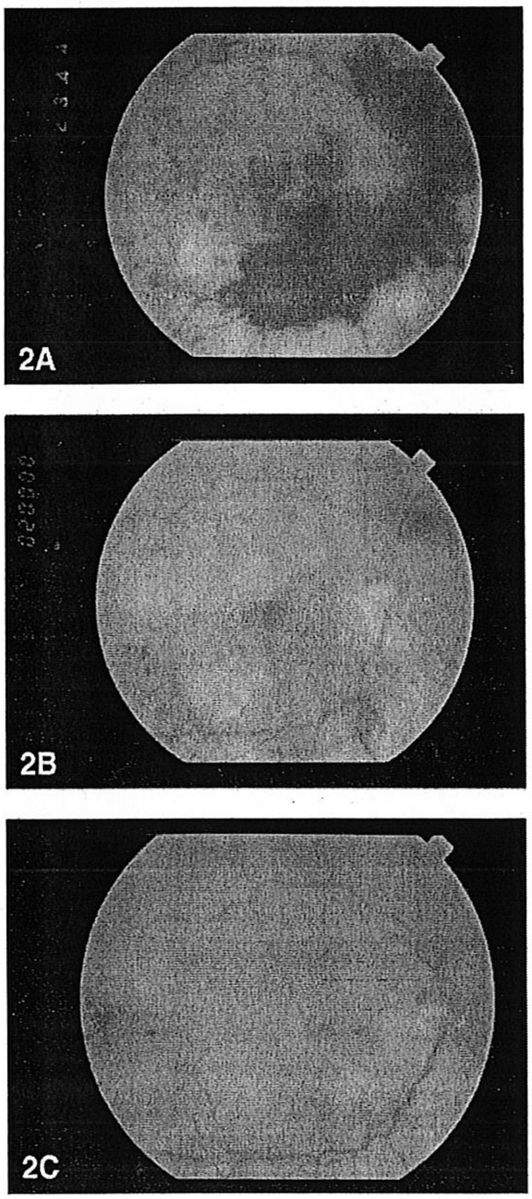
Vein Occlusion Characteristics

Visual Acuity				Tissue Plasminogen Activator		
Preoperative	*Early*[†] ($\leq$1.5 mos)	*Best*[‡] (2–6 mos)	*Final* (mos)	ml	μg	Comment
6/200	20/400 (0.25)	20/200 (3)	20/400 (6)	0.6	120	
8/200	20/400 (0.25)	20/400 (6)	20/400 (24)	1.4	280	
2/200	6/200 (1)	20/400 (6)	20/400 (24)	0.9	180	
3/200	1/200 (1)	1/200 (6)	3/200 (9) HM (12) 20/200 (24)	1.6	320	VH at 11 months; washout performed at 20 months
HM	2/200 (1)	3/200 (4)	HM (24)	4	800	
HM	20/400 (1.5)	HM (2)	6/200 (8)	4	800	VH at 1.5 months; washout performed at 2 months for hemolytic glaucoma
5/200	20/400 (0.5)	20/400 (2)	20/200 (16)	2	400	
6/200	8/200 (0.25)	8/200 (0.75)	HM (6)	4	800	VH at 2 months
6/200	20/100 (0.25)	20/100 (1)	20/100 (14)	5	1000	20/200 postoperative day 1; VH at 1.5 months (cleared)
20/400	20/80 (1)	20/40^{+1} (2) 20/50^{-3} (6) (PA=20/20^{-3})	20/30^{-3} (14)	3	600	Cataract developed
6/200	8/200 (1)	8/200 (2)	8/200 (6)	4	800	VH at 1 month (cleared)
5/200	20/200 (1)	20/200 (2)	20/125^{-3} (12)	4	800	
20/63^{-2}	20/400 (1)	20/63 (3)	20/63 (3)	4.3	860	
20/200	10/200 (0.75)	10/200 (4)	10/200 (9)	2.5	500	
HM	LP (0.25)	LP (2)	LP (5)	3.5	700	Dense VH at 1 week
20/200	20/400 (0.25)	20/100 (3)	20/63^{-3} (9)	1.5	300	
20/200^{+1}	20/200 (0.25)	20/200 (2)	10/125^{-1} (14)	4	800	
HM	5/200 (0.25)	10/200^{-2} (6)	10/160^{-2} (18)	2.2	440	Best pre-CRVO VA 20/200^{-1}
20/200^{-1}	20/80^{+1} (1)	20/80^{+1} (2)	20/160^{-1} (8)	3	600	Increased intraretinal hemorrhage and macular edema at 6 months
20/200	20/125 (1)	20/80 (3) 20/50 (6)	20/50 (8)	2.8	560	Had RD from peripheral break; treated with cryo/GFx on postoperative day 9
HM	HM (1)	5/200 (2) 10/200 (5)	20/200^{+2} (12)	3.8	760	
20/200	10/160^{+2} (1)	10/160^{+2} (2)	10/125^{-2} (12)	4	800	VH at 2.5 months, washout performed at 8 months
20/80^{-1}	10/200 (2)	20/50^{-1} (3)	20/50^{-1} (4)	3.1	620	
HM	HM (1.5)	HM (3)	HM (3)	4.5	900	
HM	10/160 (1.5)	10/200^{-2} (3)	10/200^{+1} (12)	4.5	900	
5/200^{-3}	20/160 (1.5)	20/160 (3)	20/200^{+1} (12)	6.5	1300	
HM	5/200 (0.25)	5/200 (3)	5/160 (8)	3.5	700	
10/160	20/200^{-3} (0.25)	20/200^{-2} (3)	20/200^{-2} (5)	7.5	1500	

CE/IOL = cataract surgery; CHF = congestive heart failure; ↑ Chol = hypercholesterolemia; CilAb = cilioablative procedure; COPD = chronic
HM = hand motions vision; Ht = hypertension; LASIK = laser in situ keratomileusis; LP = light perception vision; LPI = laser peripheral iridotomy;
detachment; RVO = retinal vein occlusion; TOB = tobacco use; VA = visual acuity; VH = vitreous hemorrhage.

angiographic interpretation.





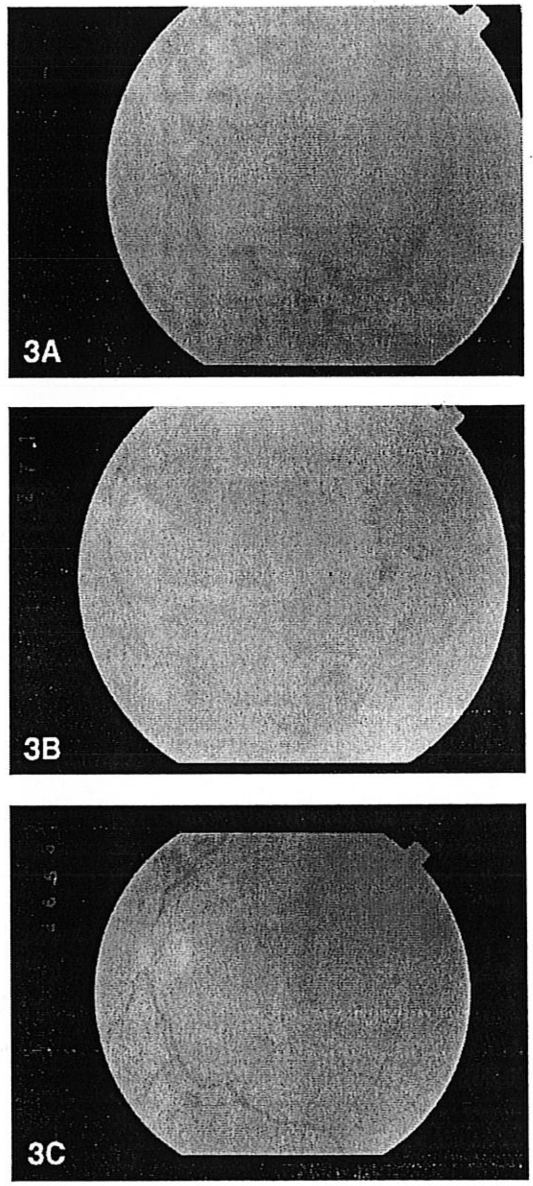


Figure 1. Setup for retinal vein cannulation with tissue plasminogen activator injection. The stabilization arm (large arrowhead) is attached to the mounting brace, which is clamped to the surgeon's wrist rest. The microcannula (small arrowhead) is held in the stabilization arm and advanced through the sclerotomy.
Figure 2. **A,** Preoperative fundus photograph of the right eye of patient 12 with central retinal vein occlusion and 5/200 Early Treatment Diabetic Retinopathy Study visual acuity. **B,** Same patient 1 month after vitrectomy with retinal vein cannulation and injection of tissue plasminogen activator showing significant clearing of retinal hemorrhage. The visual acuity improved to 20/200. **C,** Same patient 6 months after surgery showing further clearing of intraretinal hemorrhage. The visual acuity improved to $20/125^{-3}$.
Figure 3. **A,** Preoperative fundus photograph of the left eye of patient 10 with central retinal vein occlusion and 20/400 Snellen visual acuity. **B,** Same patient 1 month after vitrectomy with retinal vein cannulation and injection of tissue plasminogen activator showing clearing of retinal hemorrhage and decreased macular edema. The visual acuity is 20/80 and improved to $20/40^{+1}$ 1 month later. **C,** Same patient 6 months after surgery showing further clearing of intraretinal hemorrhage. The best-corrected acuity declined to $20/50^{-3}$ secondary to progressive cataract formation; however, the potential acuity measured $20/20^{-3}$.

study, we report the results of treating 28 eyes with vision loss secondary to CRVO with vitrectomy and injection of t-PA into a retinal vein.

Patients and Methods

Patients with CRVO referred to our office from April 1, 1998 through August 30, 1999 were eligible for the procedure if their best-corrected Snellen visual acuity was 20/400 or worse and the duration of CRVO was at least 1 month (patients 1–7). Because our procedure was a new surgical technique with unknown complications, these criteria were chosen purposely to select eyes that were likely to have a poor prognosis. After August 1999, we became more confident of the safety of the procedure, and we modified our inclusion criteria to allow patients with CRVO for as little as 1 week duration if it was associated with vision loss of at least five lines of acuity. Snellen acuity was measured from the beginning of the study until October 1999 (patients 1–11); thereafter, visual acuity was measured using the backlighted Early Treatment Diabetic Retinopathy Study (ETDRS) chart (Lighthouse, Long Island, NY). All postoperative acuities were measured using the same method used to measure the preoperative acuity of any given eye. One patient (patient 13) came from another state and was unable to return for follow-up beyond 1 week. The postoperative acuity data was obtained by a local retinal specialist who also performed standardized ETDRS acuity measurements for the patient. The only preoperative exclusion criteria were no light perception vision, active neovascular glaucoma, visually significant vitreous hemorrhage, presence of concurrent untreated or unstable ocular disease, and patient unwillingness to sign the informed consent form. No other factors (such as angiographic findings, duration of vascular occlusion, etc.) were considered to be exclusionary.

All patients enrolled in this study underwent a comprehensive ophthalmologic examination, including significant past medical and past ocular history, best-corrected Snellen (patients 1–11; Table 1) or ETDRS (patients 12–28; Table 1) visual acuity, anterior segment biomicroscopy and gonioscopy, measurement of intraocular pressure and dilated fundus examination with contact lens biomicroscopy, and indirect ophthalmoscopy. The date of CRVO onset was obtained from historical information obtained from the patient and review of records from referring physicians. All best-corrected visual acuity measurements were obtained by the two ophthalmic technicians in our office. Acuity for patients with less than 20/400 Snellen (i.e., inability to see largest projected Snellen optotype) was measured using a 20/200 "E" card held at varying premeasured distances until the patient reported visualization (the optotype was always held straight in front of the patient, but eccentric gaze was permitted). Vision was judged to be hand motions if the hand-held optotype could not be visualized at 1 foot and yet hand motions was perceived by the patient. Snellen acuity values less than 20/400 were recorded independently by each of the technicians, and when there was disagreement, the average of the two measurements was recorded. Patients with ETDRS acuity less than 5/200 (i.e., inability to see letters on the chart from a distance of 1 meter) were checked for perception of hand motions. Patients who could perceive only light or who could not perceive light were recorded as such. To quantify differences in lines of vision, all acuity values were converted to logarithm of the minimum angle of resolution (logMAR) scores, where each 0.1 logMAR unit represents 1 line of acuity. Hand motions and light perception acuity were assigned logMAR scores that were 0.1 unit (or 1 line of acuity) higher than the logMAR score corresponding to the lowest acuity measured with optotypes (1/200 Snellen, 5/200 ETDRS).

Examinations were performed before surgery and after surgery at 1 day, 1 week, 3 to 6 weeks, and monthly thereafter. Fundus photography and fluorescein angiography were performed before surgery and at 1 and 3 months after surgery in most cases. If there was a dramatic change in the status of the operative eye, fluorescein angiography was performed at the discretion of the authors. At the conclusion of the study, all preoperative and 3-month postoperative fluorescein angiograms were collected and masked by the ophthalmic technicians and were graded by each author according to CVOS criteria (nonperfused, type N; indeterminate, type I; perfused, type P; macular edema, type M)[13] with one difference: although in the CVOS, type M took precedence over type I or N (i.e., type M angiograms also could have more than 10 disc areas of nonperfusion or indeterminate perfusion[2]), in our study, types N and I took precedence over type M. Only angiograms that appeared to be perfused and to have angiographic macular edema were classified as type M. Disputed cases were jointly assigned by the authors before unmasking, and the presence of anterior segment neovascularization (ASN) took precedence over angiographic interpretation when assigning type (i.e., the category would be considered type N if any ASN were present). Characteristics of the study patients are summarized in Table 1.

Each patient underwent an extensive discussion in which the experimental nature of the proposed surgery was stressed. The written informed consent, which discussed the risks of vitrectomy surgery and the unique risks of intraocular hemorrhage from t-PA infusion into a retinal vein, was approved by the Institutional Review Board of North Broward Medical Center in Pompano Beach, Florida. All surgeries were performed on an outpatient basis by one of the authors (JNW).

A standard 3-port pars plana core vitrectomy using an illuminated infusion cannula was performed with removal of the posterior hyaloid in cases where a posterior vitreous detachment was not present before surgery. The illuminator of the infusion cannula was subsequently activated and directed toward the peripapillary area. An angled glass cannula (Micron Ophthalmic, Inc., Margate, FL) was placed in the vitreous cavity through an existing or additional sclerotomy so that the cannula was parallel to the lumen of the peripapillary branch retinal vein chosen for cannulation. (Venous branches near the optic nerve head that were clearly visible were preferred; more distal vessels were more likely to roll on attempted cannulation.) The intraocular pressure was lowered to 5 mmHg, and the branch retinal vein was pierced manually with the cannula. A bolus (average volume, 3.4 ml; range, 0.6–7.5 ml) of 200 μg/ml t-PA was injected toward the optic nerve head. A cannula stabilization system (Micron Ophthalmic, Inc., Margate FL) mounted to the surgeon's wrist rest aided in maintaining the position of the cannula within the lumen of the retinal vein during infusion, which could take several minutes to complete (Fig 1). The fluid wave through the blood vessel was visualized during t-PA infusion in every case. This wave was usually pulsatile, with injected t-PA pushing the blood column toward the central retinal vein. In the first three cases, the intraocular pressure was raised to 40 mmHg before removing the cannula from the retinal vein. However, this was found to be unnecessary because there was never intraoperative hemorrhaging in the subsequent cases in which the infusion pressure was not increased. Neither laser photocoagulation nor gas tamponade was required.

For statistical analysis, preoperative factors (patient age more than 65 years, CRVO duration more than 3 months, angiographic type, injected t-PA more than 600 μg, previous laser treatment, presence of ASN, previous vein occlusion in fellow eye, and history of glaucoma, hypertension, diabetes, coronary artery disease, or tobacco use) and postoperative outcomes (recovery of three or more lines of acuity at any follow-up, recovery of three or more lines of acuity at last follow-up, recovery of four or more

lines of acuity at any follow-up, recovery of 4 or more lines of acuity at last follow-up, and vitreous hemorrhage) were entered into a database. Logistic regression models using SAS software (SAS Institute, Inc., Cary, NC) were constructed for each variable to determine statistically significant associations between preoperative and postoperative variables.

Results

During the time of this study, 32 patients who met criteria were offered the procedure and gave informed consent. Two patients withdrew from the study before surgery. Thirty eyes of 30 patients underwent surgery. One patient with a 4-month-old CRVO and $10/125^{-2}$ acuity was found to have a central retinal artery occlusion at the time of surgery and therefore was treated with vitrectomy, retinal artery cannulation, and injection of t-PA followed by t-PA injection into the retinal venous system. Because this eye had a different surgical procedure, it was excluded from this study. Another patient (CRVO of 1 month duration and hand motions acuity) completed only 1 week of follow-up and therefore was excluded. Of the remaining 28 patients, there were 17 male and 11 female patients, ages 36 to 90 years. The study eye was the left eye in 16 patients. The average duration of vein occlusion before retinal vein cannulation was 4.9 months (range, 0.25–30 months). The range of preoperative best-corrected visual acuity was hand motions to 20/400 Snellen (patients 1–11) and hand motions to $20/63^{-2}$ ETDRS (patients 12–28). Seven eyes had ASN before surgery, three of which had some degree of iridocorneal angle involvement, with one eye having had neovascular glaucoma (patient 8). Eight patients had nine laser procedures to the affected eye before surgery, which included three grid procedures for macular edema, two panretinal photocoagulation procedures for ASN, one ciliodestructive procedure for neovascular glaucoma (this procedure and the two panretinal photocoagulation procedures were all performed by other ophthalmologists before the patients were first evaluated at our center), one unsuccessful chorioretinal anastomosis, one peripheral iridotomy, and one laser in situ keratomileusis procedure. Five eyes had a history of glaucoma (one had a prior laser peripheral iridotomy for angle closure glaucoma). Five patients (patients 6, 8, 11, 18, and 28) had a history of retinal vascular occlusion in the fellow eye. Patients 3 and 18 had a history of amblyopia in the operative eye. Eleven patients had a relative afferent pupillary defect in the operative eye. There was one preoperative vitreous hemorrhage (patient 6). However, this was judged to be visually insignificant (a small amount of organized vitreous hemorrhage in the inferior periphery with a clear view of the posterior pole). Ten eyes had a posterior vitreous detachment before surgery.

Thirteen patients had systemic hypertension, 13 had a history of tobacco use, 6 had cardiac disease requiring coronary artery bypass surgery, 4 had diabetes mellitus (patient 3 had retinopathy in the fellow eye), and 1 had an idiopathic clotting disorder.

Twenty-two of the 28 patients (79%) experienced some improvement in visual acuity during the follow-up period, and the same number had better acuity at the final follow-up examination than at baseline (Table 1). All patients had areas of clearing of intraretinal hemorrhage after surgery by funduscopy (usually first observed 1 to 2 weeks after the procedure), but to variable degrees (Fig 2). Fifteen eyes (54%) achieved a 3-line or more increase in acuity within 3 months after the procedure, and 14 (50%) had this level of improvement (average, 6.8 lines) at the last follow-up examination (Table 2). There were 10 eyes (36%) that improved by at least 5 lines of acuity at last follow-up, and 5 eyes improved by at least 8 lines. The visual acuity of patient 9 improved from 6/200 to 20/200 (5 lines) on postoperative day 1, and to 20/100 (8 lines) by 1 week. Patient 10 improved from 20/400 to $20/40^{+1}$ (>10 lines) at 2 months, and although the acuity later declined from cataract formation, the potential acuity was $20/20^{-3}$ (>12 lines) 6 months after the procedure (Fig. 3). Three eyes (patients 8, 14, and 17) had visual acuity at last follow-up that was less than baseline acuity. Vitreous hemorrhage was a contributing factor in 1 of these cases (patient 8; Table 2).

Before surgery, 10 eyes were nonperfused (type N), 9 were indeterminate (I), and 9 were perfused with macular edema (M). Of note is that three eyes (patients 6, 11, and 25) that angiographically appeared to be type I were designated type N because of the presence of anterior segment neovascularization. There were five cases in which there was no 3-month postoperative fluorescein angiogram because of vitreous hemorrhage (patients 8, 15, and 22), patient desire to forego angiography (patient 7), and failure on our part to obtain a protocol angiogram (patient 13). Of the remaining 23 cases, the preoperative type distribution based only on angiographic interpretation before unmasking was: type N, 4 eyes; type I, 11 eyes; and type M, 8 eyes. The postoperative angiographic type distribution for the same 23 cases was: type N, 4 eyes; type I, 4 eyes; type P, 5 eyes; and type M, 10 eyes (Table 3).

Table 2. Change in Vision after Retinal Vein Tissue Plasminogen Activator Injection*

Patient No.	Change in lines of Visual Acuity: *Maximum*†	Change in lines of Visual Acuity: *Last Follow-up*‡	Visually Significant Postoperative Vitreous Hemorrhage§
1	+5.0	+2.0	
2	+1.0	+1.0	
3	+7.0	+7.0	
4	−5.0	+8.0	+
5	+6.0	0	
6	+11.0	+9.0	+
7	+3.0	+6.0	
8	+1.0	−9.0	+
9	+8.0	+8.0	
10	+12.4	+11.0	
11	+1.0	+1.0	
12	+7.4	+7.6	
13	+0.4	+0.4	
14	−3.0	−3.0	
15	—	—	+
16	+4.4	+4.4	
17	−0.2	−1.2	
18	+3.6	+4.6	
19	+4.4	+1.0	
20	+6.0	+6.0	
21	+4.4	+7.4	
22	−1.6	+1.6	+
23	+2.0	+2.0	
24	0	+3.6	
25	+5.0	+4.2	
26	+7.6	+6.8	
27	+1.0	+1.0	
28	+1.6	+1.6	

*Snellen and Early Treatment Diabetic Retinopathy Study acuities were converted to the logarithm of the minimum angle of resolution scores to determine the lines of visual acuity gained or lost after the procedure.

†Based on best acuity achieved within 6 months after the procedure.

‡Average, 11.8 months, range, 3–24 months, after retinal vein tissue plasminogen activator injection.

§Vitreous washout procedures were performed subsequently on patients 4, 6, and 22.

Table 3. Angiographic Types before and after Retinal Vein Tissue Plasminogen Activator Injection*

Patient No.	Preoperative	3-month Postoperative
1	I	M
2	I	I
3	N	N
4	I	I
5	N	N
6	I (N)	M (N)
9	M	P
10	M	P
11	I (N)	I (N)
12	N	N
14	N	N
16	M	P
17	M	M
18	I	P
19	I	M
20	M	M
21	I	P
23	M	M
24	M	M
25	I (N)	M (N)
26	I	M
27	I	I
28	M	M

*Letter in parentheses indicates actual type because of anterior segment neovascularization. Only angiograms that appeared perfused with macular edema were classified as type M; indeterminate perfusion was classified as type I, and more than 10 disc areas of nonperfusion was classified as type N.

There were no intraoperative complications. Seven patients experienced vitreous hemorrhage during the follow-up period (range, 1 week–11 months). The hemorrhages were diffuse and their source was never identified. Two eyes (patients 9 and 12) had cleared spontaneously before the last follow-up visit, and three eyes (patients 4, 6, and 22) subsequently underwent vitreous washout procedures resulting in final acuities that were better than presenting acuities (by 8, 9, and 1.6 lines, respectively). Six eyes were either type N or I before surgery, and four had preoperative ASN. Patient 6 had a vitreous hemorrhage 7 weeks after surgery and experienced hemolytic glaucoma requiring vitreous and anterior chamber washout 2 weeks later. No patients in this study experienced neovascular glaucoma. Patient 20 had a macula-sparing retinal detachment caused by a peripheral break that was treated successfully with pneumatic retinopexy on postoperative day 9.

Analysis of multiple logistic regression models failed to identify any preoperative factors that were predictive or statistically associated with visual improvement of at least three lines, improvement of at least four lines, or development of postoperative vitreous hemorrhage.

Discussion

The cannulation of blood vessels and the use of t-PA for the treatment of thrombotic processes are established procedures in medicine, and retinal blood vessel cannulation has been demonstrated in animals.[14] Because t-PA given systemically seems to improve vision in CRVO[9] and may improve vision when given intravitreally,[15] it makes sense that direct administration of t-PA to the site of the thrombus via retinal vein cannulation also should be effective. Retinal vein cannulation provides several potential advantages over other methods of t-PA delivery: (1) t-PA is delivered precisely to where it is required to cause rapid lysis of the offending thrombus[16]; (2) one can be certain t-PA has reached the site because there is direct visualization of the drug infusing into retinal veins; (3) administration of a very small dose (e.g., 1 mg instead of the usual 100 mg dose given systemically) results in a local concentration near the thrombus that may be more than 100-fold higher than what could be achieved when administered systemically[17]; and (4) the flow rate achieved during retinal vein infusion may be several hundred-fold higher than normal retinal venous blood flow.[18] Therefore, this procedure provides the combination of t-PA delivered at a high flow rate (which may, by virtue of a "flushing" effect, dislodge the thrombus and allow dilation of the central retinal vein), resulting in a very high concentration of the drug at the site of the thrombus. This is achieved while giving a total t-PA dose of approximately 1% of the normal systemic dose, an amount unlikely to cause systemic hemorrhagic complications.

The natural history of spontaneous recovery of lost vision after CRVO is very poor. In the CVOS, 1% of eyes spontaneously recovered at least three lines of vision 4 months after entry into the study, 6% recovered at least three lines at 1 year, and only 24% recovered at least one line at 1 year.[2] In a retrospective study of CRVO by Quinlan et al,[19] only 19% of eyes recovered at least three lines of lost vision. In the study by Hayreh,[20] only 123 of 544 eyes with nonischemic CRVO (23%) recovered vision to a level of at least 20/200. Therefore, spontaneous recovery of a substantial amount of vision is unlikely after the onset of CRVO.

In our series, 54% of eyes with CRVO recovered at least three lines of vision within 3 months after retinal vein t-PA injection, 50% had recovered at least three lines of acuity at last follow-up (average, 11.8 months after the procedure), and 5 eyes (18%) had acuity at last follow-up at the 20/63 level or better (three of which had preoperative acuity of 20/200 or worse; Tables 1 and 2). For most patients, the improvement in vision was stable during the follow-up period.

We believe the visual recovery achieved by the eyes in our study is much better than what occurs as part of the natural history of CRVO. As part of the CVOS, a subgroup of 78 eyes with CRVO of varying duration, perfusion status (i.e., almost 21% of this group had type I or N angiograms), and baseline acuity level (between 20/50 and 5/200, a range of 12 acuity lines) were observed without intervention, and visual acuity changes were measured.[2] Spontaneous improvement in visual acuity tended to be infrequent and of small magnitude; there were only four eyes (6%) that gained at least three lines of vision compared with baseline acuity, and only two recovered at least four lines within the first year of follow-up (only three eyes reached this level of visual improvement after 3 years of follow-up). A direct comparison of this group can be made with the 17 eyes in our study for which ETDRS acuity was measured (patients 12–28). Eight eyes of this subgroup (47%) recovered at least

Table 4. Lines of Visual Acuity Improvement in Central Retinal Vein Occlusion: Natural History versus after Retinal Vein Tissue Plasminogen Activator Injection

Change in Visual Acuity (in lines)	% Untreated Central Vein Occlusion Study Patients*		% Patients s/p Retinal Vein Tissue Plasminogen Activator Injection (n = 17)†	
	4 months (n = 78)	*12 months* (n = 72)	*3 months*	*Last Follow-up*‡
≥8	0	0	0	0
≥4, <8	0	3	41.2	41.2
≥3, <4	1	3	5.9	5.9
≥2, <3	1	3	5.9	5.9
≥1, <2	17	15	11.8	23.5
≥1	19	24	~65	~76

*Reference 2.

†Patients 12 through 28 of this series, for whom Early Treatment Diabetic Retinopathy Study visual acuity was measured (also used in the Central Retinal Vein Occlusion Study).

‡Average, 11.8 months, range, 3–24 months, after retinal vein tissue plasminogen activator injection.

s/p = status post.

three lines of vision, and 7 (41%) improved by at least four lines. This magnitude and rate of visual recovery after retinal vein t-PA injection is much higher than spontaneous recovery of vision observed as part of the natural history of CRVO (Table 4).[2] Furthermore, a similar trend is seen in the first 11 patients, for whom Snellen acuity was measured. Six eyes of this subgroup (55%) recovered at least three lines of vision (based on logMAR acuity scoring) and 4 (36%) recovered at least five lines within the first year after our procedure (Table 2). Although it is true that many of the vein occlusions in the CVOS were of long duration (42% were 12 months or longer, compared with only 7% in our series), we believe our results are impressive in light of the fact that only 2 eyes in our series (7%) had baseline visual acuity better than 20/200, compared with the CVOS subgroup randomized to observation, 81% of which had baseline acuity between 20/50 and 20/200.[2] It is possible that retinal vein t-PA injection in eyes with less advanced CRVO would result in greater levels of visual recovery and perhaps better final acuity than what we have observed so far.

Masked interpretation of preoperative and 3-month postoperative fluorescein angiograms suggested a trend toward increased perfusion after the procedure, because there was a decrease in the proportion of indeterminate angiograms without a corresponding increase in nonperfused angiograms (Table 3). At least some of this effect was because clearing of intraretinal hemorrhage was often dramatic after retinal vein t-PA infusion. This would make previously indeterminate angiograms clearer for assignment to another type. However, the CVOS showed that 83% of cases with type I angiograms develop evidence of ischemia, and no "perfused" cases in the CVOS were observed to progress to indeterminate status and then to return spontaneously to perfused status.[21] Therefore, the finding that type I angiograms converted to types other than type N after this procedure is highly suggestive that retinal vein t-PA injection improves retinal perfusion.

There were three eyes with ASN before surgery that angiographically appeared to be "indeterminate," and two of these eyes appeared to be perfused after the procedure. This apparent contradiction may simply indicate the limitations of angiographic interpretation of perfusion status; perfusion and nonperfusion are probably not "all or none" clinical entities determined solely by the presence of 10 disc areas of nonperfusion. Furthermore, other factors play a role in visual recovery, such as resolution of macular hemorrhage or edema (which we believe is the reason patient 12, a type N occlusion, was able to recover more than 7 lines of acuity; Fig 2). However, it is likely that improved retinal perfusion is a prerequisite for clearance of macular hemorrhage or edema, even if such improved perfusion is not apparent on fluorescein angiography. Instruments that more accurately measure retinal blood flow may be helpful in measuring the effect our procedure has on perfusion in CRVO.

The only remarkable complications we observed were vitreous hemorrhage in seven patients (five of whom had baseline characteristics that would have excluded them from entry into the CVOS)[21] and retinal detachment in one patient. Vitreous hemorrhage spontaneously cleared in two eyes, occurred almost 1 year after the procedure (and therefore is unlikely to be related to retinal vein t-PA injection) in one patient, and occurred in one eye with a history of neovascular glaucoma and a prior ciliodestructive laser procedure. Vitreous hemorrhage was a serious complication for only one eye (patient 6), which required further surgery for hemolytic glaucoma. However, this complication may have been caused by excessive systemic anticoagulation rather than from the retinal vein cannulation procedure; the patient was taking aspirin daily in addition to the coumadin he was prescribed for his idiopathic clotting disorder. Vitreous washout in this patient and two others with postoperative vitreous hemorrhage (patients 4 and 22) resulted in final visual acuity that was better than the CRVO pretreatment baseline acuity.

The retinal detachment in patient 20 was caused by a sclerotomy-associated break and was treated successfully with pneumatic retinopexy in our office on postoperative day 9. The eye recovered six lines of ETDRS acuity within 3 months after retinal vein t-PA injection. This is the only postoperative retinal detachment we observed in the 38 procedures for CRVO we have performed to date (28 cases in this series plus the 2 excluded cases, and the 8 cases reported previously).[11,12] Considering the morbidity associated with the natural history of CRVO, we believe the complication rate is reasonable given the high level of visual recovery we have observed after the procedure.

There are several possible mechanisms to explain the results produced by this procedure, including the effect of vitrectomy, the effect of inducing fluid flow through the retinal venous system, and the thrombolytic effects of t-PA. It has been proposed that detachment of the posterior hyaloid may have a positive effect on CRVO,[22] and there are two case series (14 eyes and 5 eyes, respectively)[23,24] dem-

onstrating that removal of the posterior hyaloid may reduce macular edema in CRVO. However, the CVOS showed macular edema reduction does not correspond to significant visual improvement compared with the natural history of CRVO.[2] Furthermore, the 10 eyes in our study that had posterior vitreous detachments before surgery showed the same range of visual recovery (40% with four lines or more, 20% with six lines or more) as eyes that did not have posterior vitreous detachments before surgery. Therefore, we do not believe that vitrectomy by itself plays a large role in visual recovery in CRVO. Flushing fluid through the retinal venous system could have a positive effect independent of the thrombolytic activity of t-PA, especially in the eyes with CRVO of long duration. The only way to determine the effect of venous fluid infusion would be to randomize eyes to saline injection or t-PA injection and compare the results.

Although many factors may determine how an eye with CRVO responds to retinal vein t-PA injection (such as initial visual acuity, perfusion status, duration of venous occlusion, coexisting ocular pathologic characteristics, amount of t-PA delivered, patient age and general health status, etc.), our statistical analysis failed to reveal what these factors are. When comparing eyes that achieved at least three or four lines of visual recovery with those that did not, there was no factor associated with visual improvement that reached statistical significance. This may be because of the relatively small size of the series. Further experience may help to elucidate optimal factors and conditions for the procedure. As soon as these are known, a randomized controlled clinical trial can commence to determine how well the procedure improves the course of CRVO.

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EXHIBIT P

UNITED STATES DISTRICT COURT
FOR THE DISTRICT OF MARYLAND

RAJESH KUMAR, :

Plaintiff :

vs. : CIVIL ACTION NO.:

THE INSTITUTE OF : 2:12-CV-06870-KSH-PS
ELECTRICAL AND
ELECTRONICS ENGINEERS,
INC.,
Defendant : October 15, 2013

The deposition of GREGORY D. HAGER, taken on Wednesday, October 16, 2013, commencing at 9:29 a.m., at 3400 North Charles Street, 113 Garland Hall, Baltimore, Maryland 21218, before Shannon M. Wright, a Notary Public.

Reported by:

Shannon M. Wright

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G R E G O R Y D. H A G E R, being first duly sworn to tell the truth, the whole truth, and nothing but the truth, testified as follows:

EXAMINATION

BY MR. STAHL:

Q Good morning, Dr. Hager.

A Good morning, Mr. Stahl.

Q We met a few minutes ago. I'm Dr. Kumar's attorney in this copyright lawsuit, Rajesh Kumar v. Institute of Electrical and Electronics Engineering, Inc.

Just to define some terms off the bat, you're familiar with the acronym IEEE?

A Yes, I am.

Q Okay. That's what I will refer to the defendant as in this case.

You're familiar with the term IROS? I-R-O-S?

A Yes.

Q And do you know what that stands for

offhand?

A It's the International Conference and Robot Systems maybe. I don't remember what the acronym is in fact anymore.

Q Okay.

A But it's a conference, robotics conference.

Q Okay. And one of the subjects -- well, the subject of this lawsuit is an article that you and Danica Kragic published in 2003 in a journal of the proceedings of the IROS conference that you understand -- you're familiar with that article?

A The IROS 2003 article? Yes.

Q Yes.

A Yes, I'm familiar with it.

Q Actually, okay. I'll just refer to that, if it's okay with you, as the IROS article for the purposes of the deposition.

A Good.

Q Is that understandable to you?

A That's fine.

Q Okay. You understand you're under oath today?

A Yes, I do.

Q Okay. And obligated to answer my questions under a penalty of perjury?

A Yes, I do.

Q Okay. Just so you know, the court reporter's taking a verbatim transcript, so it's important we try not to talk over each other and that you answer verbally.

Let me start with an exhibit.

MR. STAHL: Let's call this Hager 1.

(Whereupon, Hager Deposition Exhibit No. 1, marked.)

Q The court reporter's handed you Exhibit 1, which is a subpoena that we issued in this case to you back in -- in June.

Do you recall receiving this?

A I'm sure I have. I don't recall receiving it per se, but I'm sure I've seen it.

Q Okay. You teach undergrads?
A I teach undergrads, yes.
Q And you advise doctoral candidates?
A Yes, I do.
Q And you've served as a -- a reader on Ph.D. dissertation -- for Ph.D. dissertation candidates?
A Yes, I have.
Q And you've served as a principal advisor for dissertation candidates as well?
A Yes, I have.
Q Okay. And you'd agree that one of the requirements to get a Ph.D. from Hopkins' computer science department is submission of a dissertation that reflects substantial and original research?
MR. EWING: Objection to form.
A Yes. You have to submit a thesis that contains -- we typically say publishable results.
Q And what does that mean, publishable

results?
A Results that you could submit to a peer-reviewed conference and those results would be accepted by the community as novel.
Q Okay. You were a secondary reader on Dr. Kumar's doctoral thesis?
A Yes, I was.
Q Okay. What does that mean, to be a secondary reader?
A Well, the rules have changed over the years, but what it means, I think at that time, is you had a primary advisor. So that would have been, Russ Taylor, was Dr. Kumar's thesis advisor. And you needed someone else to certify that the dissertation was adequate to satisfy the requirements of a Ph.D.
Q Someone else meaning additional committee members or member?
A Some -- some second person to read the dissertation and say, Yes, I agree, this contains sufficient material to certify -- to --

to qualify as a Ph.D.
Q Okay. You also -- you work in the CISSTERC lab? Is that the -- CISSTERC lab?
A CISSTERC.
Q Okay. And that's the engineering research center --
A For computer-integrated surgical systems and technology.
Q Thank you.
And have you been affiliated with that center since you arrived at Hopkins in 1999?
A Yes, I have.
Q Okay. And that's the same lab or center that Dr. Kumar was affiliated with as well?
A Well, that center started in 1998, so he would have been affiliated -- would have been affiliated with it.
What -- I'm pausing, because what affiliation means is a little unclear for a graduate student. That is to say, I don't know

if he got support, for example, from the grant that funded that center.
Q When you arrived in 1999, Dr. Kumar was working for the steady hand robot?
A I believe so.
Q Okay. And that robot is either located in or part of the CISSTERC?
A We had moved into or were moving into new labs right as I arrived. And yeah, the steady hand robot was sitting in the main lab area.
Q When you arrived in 1999, did you start working directly with Dr. Kumar?
A I don't recall when we were either introduced or when we started working together specifically. You know, I do know that as of, I think, early 2000, you know, there's a MICCAI paper that we coauthored. So, clearly, we were at that point acquainted with each other and must have been talking about work he was doing.
Q When you arrived in 1999, did you start

Q What do you mean by that?
A Well, I mean, the way you become a reader is either the advisor or the student asks you to be a reader.
Q Okay.
A There's no other mechanism for that to happen.
Q Do you recall the topic of Dr. Kumar's research?
A Well, his thesis covers, generally, the use of, you know, the steady hand robot and the development and use of the steady hand robot for a series of tasks.
Q And you testified earlier that to obtain certification for the Ph.D. in your department, a Ph.D. dissertation has to have a body of research that is worthy of publication or publishable, I think is the word you used?
A Yes.
Q What was publishable or original about Dr. Kumar's thesis?

A Well, in his case, he had already published articles on some of his earlier work with the steady hand robot. So, by definition, it was publishable. It had been published.
My sense of it was that, you know, he had developed an interesting systems approach to using the steady hand robot. And, in particular, this notion of direct manipulation of the robot was something that you didn't really see that much in the literature.
Q What was his interesting system approach?
A Well, you know, he had taken this idea of saying, you know, how do we make augmentation in some sense programmable? And, you know, had demonstrated that you could do that. You know, it's not an earth-shaking contribution. Clearly, we program robots all the time to do things, but it was -- you know, it was an interesting take on the problem.
Q Okay. Did this -- Dr. Kumar's thesis

contribute anything else to the field that you would consider original?
A I'd have to review his thesis in detail to remember exactly what was contained in it.
You know, the publishable pieces were primarily the -- I think the 2000 MICCAI paper, and then there were a couple of other papers more about the robot itself.
Q As a reader, I assume you actually read the thesis?
A I would have to assume so. I read it, and I signed a letter saying I had.
Q Okay. Did you read it as a draft or just in final form?
A I don't recall reading it.
Q Okay. Typically, as a thesis reader, do you read the entire thesis?
A You certainly read the entire thesis, yes.
Q Okay. You read it carefully? I mean, it's not something you skim?

A Yeah, typically, you would read it carefully. I mean, in this case, I was probably pretty familiar with what was in it before I got it.
Q I'm going to give you a copy of the thesis. This was marked as Exhibit 3 in Dr. Taylor's deposition. I want to discuss a few -- a few parts with you.
A Sure.
Q First of all, the cover, which is the second page of the exhibit actually --
A The third page.
Q Thank you.
The date of the thesis is April 2001, which I assume is the date when the thesis would have been certified?
A It's probably the date it was produced and handed in to the library.
Q Okay. Based on that date, can you estimate when you likely would have read it?
A No, I can't. It's really all over the

two years after the fact, so remembering this particular figure in Dr. Kumar's thesis seems unlikely.

Q Do you recall any discussion with Dr. Kragic at the time the article was submitted to IEEE about how figure 1 was created?

A No.

Q Other than Dr. -- Dr. Kumar's thesis, this article, and the other articles that you coauthored with Dr. Kragic, have you ever seen a task graph that contains the various states and tasks used for retinal vein cannulation?

A I'm sorry. Can you repeat the question again?

Q Have you seen, in any other published work, other than Dr. Kumar's and your work with Dr. Kragic, a task graph that decomposes retinal vein cannulation in this type of task graph?

MR. EWING: Objection to form.

A I don't have any such recollection, but it would also be surprising if you would see it,

because, in part, this reflects the architecture of the robot that we were working with.

MR. STAHL: I think we should take a short break.

(Whereupon, a recess was taken.)

Q Returning to the IROS article, Taylor Exhibit 4, tell me what this article is about.

A Sorry. Let me just make sure this is -- yeah, Exhibit 4.

Q Mm-hmm.

A Well, so, you know, I think the abstract does a good job of talking about it. So, you know, it says this research problem is to come up with a way to simply design complex surgical procedures. And so the goal was to put together a system where, you know, we were -- we were being, I guess, a little audacious in saying, you know, a surgeon could somehow, for a particular procedure, specify how they wanted to perform the procedure and then carry it out without a programmer being involved at all.

So the idea was to say, look, you need a framework that makes it easy to interactively specify and monitor what's going on, and, at the same time, ideally, you would be able to use information about how the procedure is performed. That is to say, data acquired from the robot to model that procedure.

And that really, you know, in a nutshell -- oh, I'm sorry. I'm speaking about the wrong paper, aren't I? Exhibit 4 is the IROS article.

Q Yes. What you were just --

A I was talking about -- I -- I thought you said the IJRR article. I apologize.

Let me go back and rephrase that.

Q Yeah. We're talking about the IROS article.

A Okay. So sorry. Let me go back. So --

Q Let -- let me just make sure I've got the right -- we're talking about -- is that

marked Taylor?

A I thought you had said IJRR.

Q But what does the exhibit tag there say?

A It's 4. 4 Taylor.

Q Okay. The IEEE article?

A The IEEE. I'm sorry.

Yeah. So the IEEE article is the first half of that story where we were saying how can we develop a system that makes it easy for someone to specify and monitor a task being performed by the steady hand robot? Or by, in general, a human-machine collaborative system, the steady hand robot being a specific instance of that.

Q Okay. And the abstract goes on to say it's a system that, in the last sentence, was developed and validated using the JHU steady hand robot?

A Correct. So, again, indicating the idea is to do something general. And the steady

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hand robot is a specific instantiation of the general concept.

Q What does that mean, instantiation?

A Well, so you could do what we're talking about here in any number of robots. There's nothing steady-hand specific about what we're developing. Until you actually say, okay, we're going to demonstrate it on something, you have to demonstrate on a real robot. So the demonstration is on the steady hand robot.

Q Okay. When you say it was validated using the steady hand robot, what does that mean?

A Normally validated would mean we did some type of experiment to show that the system operated as we had expected to operate.

You know, I would certainly say this paper, the validation is fairly light. So we basically say that we built it and did -- did what we expected to do. So it's not a strong validation.

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Q What was the validation?

A We implemented a task using the system.

Q Is the validation discussed in the paper, other than in the abstract?

A I don't know that the term "validation" is applied to it, but if we go through the paper -- let's go see what we did.

So we talk about task specification, and we go through and talk --

Q And, just for the record, what --

A I'm sorry.

Q Refer to the page that you're looking at.

A This is -- it's section 5. 3195 is the page number at the bottom.

Q Thank you.

A And IEEE 509 is the exhibit number.

So I have to say I -- I haven't thought about that specific question. So I myself am reading through and just seeing if we specifically talk about validation.

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Q Feel free to look through as much as you want.

I'll draw your attention to the last paragraph of the conclusion on page 3197, which says, This system is currently validated using the JHU steady hand robot as an experiment platform.

A Mm-hmm.

Q Which is essentially the same sentence you have in the abstract.

Wasn't a validation, in fact, done in connection with the publication of this paper?

A Well, again, the validation is we've been able to implement this on the robot. And as I read through, we basically go through and say here's how you do this, here's how you do this.

The final paragraph of the paper before the conclusion where it talks about the keyboard buttons basically says, you know, here's how we simulate the user pushing the buttons. Or the

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event -- here's how we get the event, which is simulated by pressing the buttons.

So the validation really is just that we were able to implement it on a particular robot. In this case, the steady hand robot.

And I'm going to go on to say this example task is analogous to many task. So, again, the point of the paper was really is to say here's a general framework, here's a system that you could implement this framework on, and then here's an example of something you could do having implemented the system on that robot.

Q Was the system actually implemented on the robot at the time this paper was -- was submitted?

A I don't know how mature the system was at that point. Again, Dr. Kragic was doing the implementation. And, clearly, she had a system up and running, because she's got pictures of the GUI, for example, for the system. But what level of functionality it had at that point, I

do not know.

Q I mean, do you know if she actually used the steady hand robot applying this system?

A You know, it says it's been implemented or validated, whatever the term is, on the steady hand robot, so --

Q Right. I see that, but what I'm asking you is was the system actually applied to operate the robot at the time this paper was submitted?

A I don't have a specific recollection of, you know, what level of implementation was there. So I couldn't tell you for sure if everything was running on the steady hand robot, or if pieces were running on the steady hand robot, or not.

Q Okay. At some point did Dr. Kragic or yourself run this system and run experiments using this system with the steady hand robot?

A I think so, but I don't remember myself being involved in it. So I can't tell you when

or at what level of functionality again.

Q Okay. Were you present when -- at any time when Dr. Kragic actually operated the steady hand robot?

A I don't remember. I mean, at the time, the lab was in the basement. My office was on the third floor. So my appearances in the lab when people were doing work was not that common.

Q Okay. Do you know whether Dr. Kragic operated the steady hand robot using the MRC software library we talked about earlier?

A I -- I don't know how she interfaced to the robot.

Q Okay. Can you go back to the first page of the article, please?

A Sure.

Q In the first page on the second column, the article describes -- one, two, three, four -- Roman numeral 5, features of the system. It says system has to be modular, appropriate, flexible, scalable, and have a theoretical

foundation.

Do you see that?

A Yes.

Q Okay. What does it mean for the system to be modular?

A Well, in this case, as it says -- I mean, this is a pervasive concept in computer science. So modular simply means that you can take a complex functionality and break it down into components. So we talk about writing modular code all the time.

So, in this case, it's modular in the general computer science sense that you can take a complex task and you can break it down into a set of smaller, reusable components that you can then compose to produce a complex task.

Q Okay. And just to be clear, we're talking about software architecture?

A Yes.

Q Okay. What does it mean for the system to be flexible?

A Well, so here, as it says, the system should be flexible to allow users to easily change the existing model for the task they want to perform.

So this goes back to what I was saying earlier. You know, our notion was eventually a surgeon should be able to specify what they want the system to do. So it should be easy for them to put together a model for a task, and then somewhere down the line say, I don't like that, change it, and put together a new model.

Q And the idea is you have different software components that can be mixed and matched, as it were, for whatever process the surgeon wants to apply?

A Correct. And, you know, that's part of the reason we had the GUI and we used the XML framework, is because it -- it allowed a nonprogrammer to specify the behavior of the robot.

Q Point 4 refers to the system being

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describes the syntax. So now that you have a syntax, you can actually write a specification for a graph. And so the -- it's a pseudo XML representation, which probably means she elided certain portions of this syntax to make the figure more readable, but it's -- it's the -- the representation of the graph that would be implemented by the system.

Q Who prepared -- I'm sorry.

You said she prepared it. You mean Dr. Kragic prepared this pseudo XML representation?

A Again, I didn't prepare it, so, presumably, she did.

Q Okay. Do you know when she would have put it together?

A Before the paper -- before we wrote the paper, but I don't know when it first appeared, you know, as a -- as a recognizable object.

Q Sometime after her arrival at Hopkins, but before the paper was submitted?

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A Correct.

Q Do you know how long it took her to prepare this?

A No.

Q Based on your experience, looking at the pseudo XML representation now, can you tell me how long it would take to prepare something like this?

MR. EWING: Objection to form.

A I don't know. I actually don't use XML myself, so I have really no experience whatsoever.

Q Can you say whether it would be minutes versus days, versus weeks, versus months?

MS. TURNER: Objection --

MR. EWING: Same objection.

MS. TURNER: -- based on his answer.

A No.

Q Okay. Turn to the references, please, in the article.

Citation 6 in the paper is Dr. Kumar's

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thesis; is that correct?

A That is correct.

Q Okay. Citation 5 is to the Hundtofte article that, I think, we looked at earlier.

Is that the same article?

A Yes, I believe so.

Q Okay. And feel free to look, but I suspect you will recall.

On the second page of the article, there's reference to citation 5 and citation 6. And those are, in fact, transposed?

A Well, there's -- so it, first, says this paper builds on research presented in 5 and 6, so those, obviously, can't be transposed. There's no transposition possible there.

Q Right. Keep on going. Next paragraph.

A And then, yes, there's a point where we transposed 5 and 6 where we mistakenly say that 6 is the HMM modeling and 5 is the Kumar thesis.

Q Okay. How did you come to work with Dr. Kragic?

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A So I knew her thesis advisor, Henrik Christiansen, who's now a professor at Georgia Tech. And he had a large lab. She was in that lab, and she was doing work in visual servoing. She was interested in that. And at the time, I was well-known in that area.

So I believe -- and, again, I don't have an iconic memory of this. -- at some point he probably introduced us. And then as things progressed, she did her Ph.D. thesis, and he invited me to be a -- I think it's actually called a defendant on her thesis. It's a little different process there than it is here.

Q But is it the same idea? You were a reader?

A Well, you read the thesis. In their system, you actually defend the thesis for the candidate.

Q Good deal.

And so how did she come to be at Hopkins?

have made in response to any peer-reviewed comments?

A We would have potentially revised the article, but I don't remember what process we went through to do that.

Q Can't recall any specifics?

A No. There may be an email trail. I just don't remember as I sit here.

Q Okay. New topic.

At some point, did you become aware that Dr. Kumar had raised some concerns about the IROS article and the IJRR article?

A Yes.

Q When did you first hear that?

A I believe there's an email, in fact, that places it at the end of 2010. So December 2010.

Q Showing you what's been marked as Taylor Exhibit 6. Sorry.

Is that -- is that the email that you're referring to?

A Yup.

Q Okay. So on December 9th, 2010, Dr. Kumar sends an email to Dr. Russ Taylor saying here are the papers you talked about, and Dr. Taylor forwards it to you, right?

A Yes. That's what's here.

Q Okay. And from the first paragraph, you say, A few quick things I didn't realize when we talked.

This email was preceded by a discussion between you and Dr. Taylor?

A Yes.

Q Okay. Tell me about that discussion.

A It took place -- my recollection, it took place in Russ's office. He just said, you know, just to let you know -- and it was a little bit of a complicated conversation, because he had had a discussion with Dr. Kumar. He wasn't entirely sure what level of confidentiality Dr. Kumar had assumed of that discussion. And so he was somewhat oblique and

just said that Dr. Kumar had expressed some concerns about a paper we had written vis-a-vis his thesis. And it wasn't -- wasn't long and -- because he wasn't sure what he could say. It was a little hard to actually parse out what had transpired.

Q Okay. What did you say?

A Well, I was obviously extremely concerned. I -- you know, I had a lot of respect for Dr. Kumar. I certainly do my best as a professional to make sure that we, you know, publish and reference people as appropriate.

And so when Dr. Taylor first presented it to me, I thought he was saying we had completely dropped any citation to Dr. Kumar's work. And so I was extremely concerned and almost alarmed.

So then I went back and I looked, and I realized, no, that that wasn't the case. In fact, we had referenced him in the IEEE article.

you know, it's not obvious that they're completely unrelated to each other.

Q Okay. So it might not be obvious, but the similarity is troublesome?

MR. EWING: Objection to form.

A The similarity is apparent.

Q Okay. Well, you used the word troublesome here.

MR. EWING: Same objection.

A I used the word troublesome, but, you know, that's more a literary flourish, I think, than anything.

Q And how about when you called it the same enough, is that a literary flourish as well?

A I'm sorry. Same enough. Oh. It's same enough to wonder why. No. If you take it out of context, it's the same enough to wonder why meaning I can see how someone would look at it and think they look quite similar.

Q You say Dani would have produced it,

but you would have to find out from her what happened.

Did you at some point follow-up with Dani?

A At some point I did. I don't think it was at this point.

Q Okay. So it was troublesome, it was the same enough to wonder why, but not the same enough for you to immediately contact Dr. Kragic?

A Because when I had the discussion with Dr. Taylor, there was this whole discussion of what is confidential and what's not confidential. So, obviously, reaching out to Dr. Kragic, she would say, well, why do you care about this? And then I have to open up that whole discussion.

So I think at least part of it was at this point, there was just a lot of ambiguity about how -- you know, what -- what -- what really was Dr. Kumar's concern, because I had

not talked to him directly. I only had this discussion with Dr. Taylor. And what level of confidentiality Dr. Kumar had assumed that conversation had, i.e., should I even be hearing this from Dr. Taylor.

So that kind of froze us. And then it's mid-December, so I'm sure we went off to Christmas holidays and New Year's. So time passed.

Q Well, in fact, over a year passed before you contacted Dr. Kragic about this.

A Certainly.

MS. TURNER: Please don't argue with the witness.

MR. EWING: Objection to form.

A But these --

Q That's correct, right? I mean, it was over a year before you contacted Dr. Kragic?

A I don't remember when I contacted her.

Q Well, we'll look -- we'll look at the documents.

And it's your testimony that the reason you waited to contact Dr. Kragic for however long it was is because of confidentiality concerns?

A Yeah. So yeah. One of the things that we talked about was, you know -- and I think you have email to this effect. -- that Dr. Taylor was suggesting to Dr. Kumar that he should discuss it directly with me, which seemed like an appropriate step to take at the time.

So -- and, you know, very curiously, I was meeting with Dr. Kumar during this time on other projects. And so I kind of naturally expected him to -- to bring it up, and he never did. So it continued to live in this space of it's not clear if Dr. Kumar believes that I should know about this via Dr. -- his discussion with Dr. Taylor. And if I bring it up, then, obviously, I'm exposing Dr. Taylor's confidence in me, which was one of his concerns.

Q So you met with Dr. Kumar subsequently,

IJRR reviews that you did receive?
A Yes.
MR. STAHL: Okay. That's all I have.
(Whereupon, examination concluded at 2:45 p.m.)

CERTIFICATE OF DEPONENT

I hereby certify that I have read and examined the foregoing transcript, and the same is a true and accurate record of the testimony given by me.

Any additions or corrections that I feel are necessary, I will attach on a separate sheet of paper to the original transcript.

____

GREGORY D. HAGER

STATE OF MARYLAND SS:

I, Shannon M. Wright, a Notary Public of the State of Maryland, do hereby certify that the within named, personally appeared before me at the time and place herein set out, and after having been duly sworn by me, was interrogated by counsel.

I further certify that the examination was recorded stenographically by me and this transcript is a true record of the proceedings.

I further certify that the stipulations contained herein were entered into by counsel in my presence.

I further certify that I am not of counsel to any of the parties nor an employee of counsel nor related to any of the parties nor in anyway interested in the outcome of this action.

As witness my hand and notarial seal this 18th day of October 2013.

My commission expires
July 26, 2015 --------------------
Shannon M. Wright

INDEX OF EXHIBITS

INDEX OF EXHIBITS (cont'd)

EXHIBIT Q

UNITED STATES DISTRICT COURT
FOR THE DISTRICT OF MARYLAND

RAJESH KUMAR, :

Plaintiff :

vs. : CIVIL ACTION NO.:

THE INSTITUTE OF : 2:12-CV-06870-KSH-PS
ELECTRICAL AND
ELECTRONICS ENGINEERS,
INC.,
Defendant : October 15, 2013

The deposition of RUSSELL H. TAYLOR, taken on Tuesday, October 15, 2013, commencing at 9:32 a.m., at 3400 North Charles Street, 113 Garland Hall, Baltimore, Maryland 21218, before Shannon M. Wright, a Notary Public.

Reported by:

Shannon M. Wright

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R U S S E L L H. T A Y L O R, being first duly sworn to tell the truth, the whole truth, and nothing but the truth, testified as follows:

EXAMINATION

BY MR. STAHL:
Q Good morning, Dr. Taylor.
A Howdy.
Q I'm Eric Stahl. I represent Dr. Kumar, Rajesh Kumar, in this matter.
Let me start by asking you if you've ever had your deposition taken before.
A Mm-hmm.
MS. TURNER: Yes or no --
A Yes.
MS. TURNER: -- please.
A Yes. I'm sorry. My mouth was full of coffee, so --
Q Okay. So they probably told you in the last -- last time you were deposed, you need to

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answer verbally so that the court reporter can make a proper transcript.
You understand that?
A Yes.
Q Okay. And you understand you're under oath and obligated to answer my questions truthfully?
A Yes.
Q Okay. If I ask a question that you don't understand, let me know, and I will try to ask a better question.
Can we agree on that?
A Okay.
Q How many times have you been deposed before?
A Oh, several. In expert witnessing, it was, I think, three, maybe four. I -- I -- maybe -- I -- it's that order.
Q Okay. Mostly -- mostly as an expert witness?
A Yes, as an expert witness.

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Q Have you ever testified as a fact witness or a party in a copyright lawsuit?
A In a -- no, I have not in a copyright lawsuit.
Q Okay. Well, you understand we're here today in connection with Dr. Kumar's copyright infringement case against the Institute for Electrical and Electronics Engineers?
A Yes.
Q And I'm going to refer to them today, the defendant, as IEEE.
That's an abbreviation you've heard before?
A Yes.
Q Okay. Do you have any understanding as to what this lawsuit is about?
A I've read the complaint.
Q Okay.
A And I understand that Dr. Kumar is alleging copyright infringement.
Q That is true.

closely than the other readers with the student in -- in the preparation of the thesis, and usually has a great deal of say over whether and when the student will defend it.

I should add that here at -- especially within the ERC, we do a great deal of co-advising. And -- and so some of the people who are readers are -- are more or less actively involved with -- with the student.

Q Okay. You made a distinction between the advisor and the reader.

I understand -- as I understand it, a thesis typically will have multiple readers or secondary advisors; is that -- is that correct?

A That's correct.

Q And leaving aside the practice in your lab of having co-advisors, is it typical -- what is the typical role for a secondary advisor or reader?

A Well, largely, the role is to certify that this dissertation meets the standard of

quality that one would expect in a -- to be associated with a dissertation in support of the degree of doctor of philosophy. I believe it -- I believe the wording is something like in partial fulfillment of the requirements for the doctor of philosophy.

Q And you're using the term dissertation, and you've also used the term thesis.

Are they interchangeable?

A I think technically, in my mind, there's a small distinction, but the terms are normally used interchangeably.

To me, a thesis is a proposition, and a dissertation is a document describing this proposition and the -- and describing the evidence that you're using to support the proposition.

Q Okay. So the published document is --

A Is the -- is I think, technically speaking, the dissertation, but is it very frequently just simply referred to colloquially

as a thesis. So the terms tend to be used interchangeably.

Q Okay. What are the requirements to have a dissertation certified for the Ph.D. computer science degree?

MS. TURNER: At Johns Hopkins?

MR. STAHL: At Johns Hopkins. Thank you.

A I don't know what you mean, what are the requirements.

Q Well, you -- I think the term you used earlier was the standards.

So, in your mind, what are the standards for certifying a dissertation that meets the requirements of the Ph.D. degree in computer science from Hopkins?

A Okay. They're not -- I'm not sure that there is a single written description.

Q Okay.

A Generally, I think that the -- that a dissertation should constitute a -- or a thesis,

or whatever, should constitute a -- a contribution to knowledge. And in the case of an engineering thesis, it usually is -- well, I'm not sure I really can give you an objective answer, because it is so much a subjective opinion based on -- on almost an overall gestalt an understanding.

Q Okay.

A But, generally speaking, there should be some independent contribution to knowledge or engineering practice. And normally there should be some element of generalizability.

Q General- -- I'm sorry?

A Generalizability. That you -- I don't think you get -- you should get a Ph.D. just simply for implementing a big system or writing a big computer program, unless -- so that computer program, or whatever, that dissertation, needs to have some -- some element of general knowledge. You should -- compared to what was known before.

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Q It's got to be something new?
A It should -- it needs to have at least some novel element. Some theses have more novelty than others, but it needs to have some novel element.
Q Some element of original research?
A Yeah.
MR. STAHL: Mark this as Exhibit 1.
(Whereupon, Taylor Deposition Exhibit No. 1, marked.)
Q And the court reporter's handed you what I've marked as Exhibit 1.
A Mm-hmm.
Q Which is a document that says at the top, "Ph.D. Requirements - Computer Science," and I'll tell you I found this last week on the departmental website.
A Mm-hmm.
Q Is this a document you recognize?
A Well, it appears to be taken from our website, and it seems to be sort of general

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guidelines for the Ph.D. program.
MS. TURNER: But the question was whether you recognized it.
A I don't actually know. I mean, I -- I think I've seen it. I've seen pieces of it before on the web. I don't think I've sat down with it printed out in this form.
Q Okay. Is there a formal written description of the requirements for getting a Ph.D. in computer science at Hopkins?
A Well, this appears to be a description of departmental process that -- at least some of this was, I think, evolved since Dr. Kumar was here. But this could -- appears to be a description of -- of the current practice.
Q Okay. At the bottom of the page in the footer, there's a web address or URL that has -- it says www.cs.jhu.edu.
A Mm-hmm.
Q And that's the domain for the computer science department here at Hopkins, right?

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A Mm-hmm.
Q And it says /, there's a tilde and Ja- --
A Tilde.
Q -- Jason. Right. That's tilde Jason. Sorry.
We can't talk over each other for the court reporter.
A Okay.
Q Court reporter's sake.
Is Jason a person or a server, or do you recognize the domain here?
A That's Jason Eisner, who is a faculty member within the computer science department.
Q Okay. Do you think this is something he put together, or is it just living on his page?
A I think it's something he put together.
Q Okay. Well, I wanted to ask you, in any event, about page 8 of the document.
You see the section that says, "Final

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Year: Thesis" --
A Mm-hmm.
Q -- "Thesis Defense, and Revisions"?
It says here that "The Ph.D. thesis is a dis-" -- I'm sorry.
"The Ph.D. thesis or dissertation is the signal achievement of the Ph.D. degree."
Are you with me?
A Mm-hmm.
Q Okay. Next sentence says, "It is a large, careful, and substantive piece of original work."
A Mm-hmm.
Q Is that an accurate description, in your experience, of what a Ph.D. dissertation at Hopkins requires?
A Requires a substantive -- yeah. I mean, it has to be a substantive piece of work, and has to have an element of originality in it.
Q Okay. And that was true in 2000-2001 as well?

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A That -- that it had to have an element of originality, yes.
Q Okay. Second paragraph, the third sentence says, "Writing this document is a satisfying way to wrap up your graduate experience, but it is itself a considerable creative act requiring plenty of time."
Is that true today with respect to preparing a thesis in your department?
A Requires plenty of time usually, yes.
Q And it's also a creative -- considerable creative act?
A There needs to be an element of creativity or originality in the document.
Q Okay. And that was true in 2000-2001 as well?
A That -- that there needed to be an element of originality in the document, yes.
Q Would you agree that computer science department in the Johns Hopkins wouldn't grant a Ph.D. to a candidate whose thesis was not

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original?
MR. EWING: Objection to form.
Q You can answer.
A Could you repeat the question?
Q Would you agree that the computer science department here at Hopkins would not grant a Ph.D. to a candidate whose dissertation was not original?
MR. EWING: Same objection.
A The expectation is that there be an element of originality in -- in a Ph.D. dissertation.
Q Okay. Lacking originality, the Ph.D. would not be granted?
A If there was no originality --
MR. EWING: Objection to form.
A If there was no originality, I believe it is unlikely that the committee would -- would approve it.
Q The computer science program at Hopkins would not grant a Ph.D. to a candidate whose

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dissertation did not contain substantial research; would you agree?
MR. EWING: Objection to form.
A You're using words like substantial, which really comes down to a question of degree. Some theses are more original than others. Some theses have more substantial contributions than others. Some have more significant contributions than others. There is a threshold that is a judgment call.
Q Okay. Would you agree that the -- that computer science department at Hopkins would not certify a Ph.D. dissertation that contained no new insights?
MR. EWING: Objection to form.
A No new insights? What do you mean by an insight?
Q New contribution to the field.
A You need to have some contribution to the field.
Q Okay. Members of a -- of a thesis

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committee, I take it, are obligated to read the dissertation carefully?
A Yes.
Q And, in practice, they do, in fact, read the dissertations carefully?
MS. TURNER: Objection.
A I -- I -- I can't know what all members of all theses committees do. All -- all generally do read the thesis, but how thoroughly? How deeply? Do they go into the footnotes? I can't tell you what other people do.
Q Let me ask you about your practice when you were a -- either an advisor or a secondary reader.
Do you typically read the entire thesis carefully?
A I try to.
Q Okay. I mean, it's not something that a reader, you know, sitting on a committee would typically skim just to get the gist of?

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Q Okay. And my question is, looking at the list of names here in the acknowledgment section of the dissertation, does that refresh your recollection as to who else may have signed off on the thesis?
A Not really. I -- I -- I -- I don't know if all of the people listed here would have signed the thesis.
The -- the normal practice of how many people sign has evolved over the years in computer science, and I just don't remember.
Obviously, he's acknowledging these people as -- as having contributed to his work.
Q Okay. Can you turn to page 6?
MR. EWING: Roman numeral 6, or --
MR. STAHL: No, no. Regular 6.
MR. EWING: All right.
Q Section 1.3, you see that problem statement? Are you with me?
A Mm-hmm.
Q Yes?

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A Yes.
Q Okay. What is a problem statement in the context of a dissertation?
A Well, I don't think it has a specific technical meaning in the context of a dissertation, but, roughly, what I believe is going on here is he's laying out the problem that -- that he believes his research will help him solve.
Q Okay.
A Or will help him improve or whatever.
Q Okay. So this is a statement of what the dissertation is -- is -- of the problem the dissertation is attempting to address?
A I would say that's a fair characterization.
Q Okay. In the italicized language about halfway down the -- the page, he describes the problem as -- I'll just read. -- generate a set of generic robust primitives, and ways to combine them to transparently implement explicit

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specifications for simple manipulation tasks.
Do you see that?
A Yes.
Q Okay. What -- do you have an understanding as to what he means by generic robust primitives?
A I believe what he must be referring to here are control laws for the -- for the robot.
Q Mm-hmm. What's a primitive?
A It's -- I suppose you could -- you lawyers may refer to it as a term of art. Basically, it's -- it's a building block or an element that it's there and you -- you build other -- other things out of it.
Q And this is in the context of instructing a robot how to -- how to operate? Simple computer instruction for that?
A Yeah. In this case, I believe it refers to control laws for the -- for the robot.
Q Okay. And what does it mean for the -- for a primitive to be robust? Is that a term of

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art?
A To some extent, it's a buzz word. Here, I believe what it means is that these primitives can be -- or these control modes can be counted on to act in a predictable way within the context of some set of assumptions.
Q Okay.
A And -- and that the computer code is well-debugged.
Q Okay. Let's jump to page 19. This is a section titled, "Contributions."
And the first question is -- I have is, is it typical for a doctoral thesis in your department to list the contributions that the paper is making?
A Yes.
Q Okay. And what does the term contributions mean in this context?
A It generally is some element that is intended to be part of the argument as to why you should -- you should give someone a Ph.D.

So these are the elements that are considered significant enough contributions to the state of the art. Some are -- may be big contributions, some may be little contributions, but I think the argument is taken together. They're enough of a contribution that you're willing to give -- say this person can -- can be called a doctor of philosophy.

Q Okay. Fair to say these are the elements of the thesis that are original enough and enough of a contribution to the field to, as you say, merit getting the Ph.D.?

A Yeah.

Q Okay.

A Yeah.

Q Take a second and read page 9 for me, please.

A Okay.

Q Okay. Would you agree that this section, this page 19, accurately reflects the original contributions of Dr. Kumar's thesis?

A They reflect the contributions of the thesis. There are different degrees of originality.

Q Okay. Well, let's -- let's -- let's break that down.

The first bullet point suggests that the thesis contributes an implementation of a simple framework for task-level specification.

A The first -- he says he -- he -- he designed and implemented a framework in that stroke.

Q Okay.

MS. TURNER: Let's wait for the question.

THE WITNESS: I think he -- I think he was done.

MR. STAHL: There was a question mark.

MS. TURNER: Okay.

Q Okay. Well, in what way and to what degree was Dr. Kumar's framework for implementing task-level specification original?

A It was not -- certainly not the first occasion when -- when that idea had been reported. I think the contribution here is that he -- he did it and provided the framework that he could then apply to the remaining bullets here.

This is not uncommon in a Ph.D. thesis that one of the contributions -- I'm sorry. I interrupted because there was someone at the door there.

It is not unusual in a thesis for one of the contributions to be I implemented a -- a -- a -- an experimental framework for the remaining parts of my thesis.

Q The last sentence of that bullet, first bullet point, says, This creates a useful flexible system for performing simple manipulation tasks in environments with detectible interactions.

Would you consider the flexible system reported here to be an original contribution of

Dr. Kumar's?

A The notion of it being flexible was original? No.

Q No. The system itself.

A That system had not previously been implemented, and he implemented it to provide an experimental framework for the rest of his thesis.

Q Okay. Was that original?

A What do you mean by original?

No one had implemented that framework before. He implemented that framework.

The concept of a hierarchical decomposition into subtests, each of which has a characteristic control law or behavior with -- with transition criteria to other submodes or subtasks, or whatever you want to call them, was certainly in existence before Dr. Kumar implemented it.

Q Okay. So what about it was a sufficient contribution to merit recognition as

of taking some complicated thing and breaking it into subparts.

Q Okay. And in the context of the work being described in this thesis, do you agree with Dr. Kumar's statement that it can be a hard problem to decompose a task into its subparts?

A That can be monitored and executed simultaneously.

Q Okay. You agree with that?

A It can be.

Q Okay. Let me ask you. Is decompose a term of art in this field?

A I think it's a general engineering term that means to break something into simpler pieces.

Q Okay. Can you describe for me why it can be a hard problem to decompose a task into subparts that can be monitored and executed simultaneously?

A Hmm. Why can that be hard?

I have not studied carefully what

Dr. Kumar is talking about here, but I would -- at least in this specific context of this thesis.

But one thing that can happen is if -- is sometimes you're monitoring an execution of -- two aspects of a task can conflict with each other. And you have to be sure that however you're breaking things down don't cause conflicts. Or, if they do, you'll have to have a mechanism for resolving those conflicts.

Q Okay. And is it fair to say that part of the problem is this is all about instructing a robot how to operate, and you need to be really explicit in how you break down the tasks so that the robot operates like you want it to? Is that what this is about?

A I think so.

Q And is it fair to say that one of the contributions of Dr. Kumar's thesis was its use of task graphs to instruct a robot how to perform tasks composed of multiple subparts that

need to be monitored and executed simultaneously?

MR. EWING: Objection to form.

A Could you rephrase or clarify the question?

Q I'll try to repeat it.

Is it fair to say that one of the contributions of Dr. Kumar's thesis is its use of task graphs to instruct a robot to perform these multipart tasks composed of a sequence of actions?

A Dr. --

MR. EWING: Same objection.

A Dr. Kumar showed that you could control a steady hand robot to perform tasks using this task graph formulation.

Q Okay. And was that an original contribution of the thesis?

A The -- the application to -- to steady hand robot for micromanipulation surgical tasks was.

Q Okay. Take a look at page 41.

A Yes.

Q The -- do you see figure 4.3?

A Yes.

Q Read as much of the surrounding text as you need to, but my question's going to be, do you -- can you describe what's being shown in figure 4.3?

A Okay. This is one possible diagrammatic description of what is an extremely common concept in robotics. The idea is you have primitive actions, and, if an event happens, it can cause you -- cause the control of the robot to shift to another primitive action or primitive control mode of the robot.

Q Do you know whether figure 4.3 is original to Dr. Kumar?

A It is not.

Q Okay. Do you know where it came from?

A Figures like this have been used in robotics discussions on chalkboards or

Q And that decomposes the tasks for retinal vein cannulation.
A With bubbles and transition arrows?
Q These bubbles, these transition arrows, and these tasks, and this decomposition.
MS. TURNER: Okay. We need to be very precise here. When you say these bubbles, you're saying the bubbles that appear in figure 5.13 specifically.
These bubbles was the reference.
Q Let me restate the -- let me restate the question, because no, I don't want to be focus on bubbles.
But -- but the tasks and the relationship among them displayed in a task graph showing retinal vein cannulation, is that something you've seen outside the context of this thesis?
A Let me -- can you just repeat, or let me repeat my understanding of the question?
Q That might be helpful.

A Have I ever seen another figure that uses bubbles and transition arrows to describe the process of retinal vein cannulation? Yes.
Q Using the same decomposed tasks and the same relationship to each other?
Is your answer still yes?
MS. TURNER: Objection.
A Using the -- what do you mean by the relationship to each other?
Q The tasks in this order, in this -- in this sequence.
A With those -- with those transition arrows?
Q Yes.
A No.
Q Okay. Taking out the transition arrows, you have seen a task graph that resembles this one?
MS. TURNER: Objection.
Q Well, you answered yes a moment ago.
What were you referring to in your --

in your prior answer?
MS. TURNER: And, again, I'm going to object. His answer goes with his question, and now you're asking a different question. One that's not clear to me.
Q Okay. Well, let's -- let's -- let's back up.
Have you ever seen any task graph describing the tasks for performing retinal vein cannulation in the context of a robotics paper anywhere?
A Yes.
Q Okay. Other than in the thesis, where have you seen it?
A Well, there was a paper, the IROS paper, that is, I believe, one of the elements of this lawsuit.
Q Okay. And we're going to look at that before the day is done.
Other than in the IROS paper, anywhere else?

A I believe there was an IJRR paper.
Q One coauthored by Dr. -- Dr. Hager?
A Yes.
Q Okay. Other than those two papers, anything else?
A I really don't recall; although, it is possible.
Q Okay. Again, setting aside what is possible, I'm asking you have you ever seen any task graph on instructing a robot to perform the tasks for retinal vein cannulation anywhere other than the thesis and the IJIR -- I'm sorry -- IJRR and IROS articles coauthored by Dr. Hager?
A In print?
Q Let's start in print.
A Okay. I don't recall any.
Q Okay. Take off the qualification of in print, have you seen it anywhere?
A I don't recall anything specific, but, again, it is possible.

bubble.

And do you know why that appears in both places?

A No. It looks -- it looks to me like he's saying that insert if I get to -- it looks to me like he may be us- -- it's possible that he's using it to mean something different. That the insert is insert until you contact the retina. And then it's possible that this other contact is follow the rules for moving the robot while you are in contact with the retina.

Q Okay.

A At least that's possible, but I'd have to go back and look in his thesis if he actually explained what he meant.

Q Okay. So just to sum up. Figure 5.13, to your understanding, depicts the process through which the steady hand robot can be used to aid in retinal vein cannulation?

A It depicts a process in which it could be used.

MR. EWING: I have nothing further.

THE WITNESS: Okay.

MR. STAHL: I have no questions.

THE WITNESS: Okay. Done.

MS. TURNER: Do you prefer to read your deposition before it's --

THE WITNESS: Should I?

MS. TURNER: Why don't we read it?

THE WITNESS: Yeah, I think it would be a good idea.

(Whereupon, examination concluded at 1:59 p.m.)

CERTIFICATE OF DEPONENT

I hereby certify that I have read and examined the foregoing transcript, and the same is a true and accurate record of the testimony given by me.

Any additions or corrections that I feel are necessary, I will attach on a separate sheet of paper to the original transcript.

____

RUSSELL H. TAYLOR

STATE OF MARYLAND SS:

I, Shannon M. Wright, a Notary Public of the State of Maryland, do hereby certify that the within named, personally appeared before me at the time and place herein set out, and after having been duly sworn by me, was interrogated by counsel.

I further certify that the examination was recorded stenographically by me and this transcript is a true record of the proceedings.

I further certify that the stipulations contained herein were entered into by counsel in my presence.

I further certify that I am not of counsel to any of the parties nor an employee of counsel nor related to any of the parties nor in anyway interested in the outcome of this action.

As witness my hand and notarial seal this 28th day of October 2013.

My commission expires
July 26, 2015 ---------------------
Shannon M. Wright

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EXHIBIT R

Ph.D. Requirements - Computer Science

October 16, 2003 - last edited August 6, 2013

Introduction

This web page explains how our department's Ph.D. program is structured. It also gives additional details of department and university practices, beyond the formal Ph.D. requirements outlined in the course catalog. Substantive policy changes will be reflected on this page, and major ones will be announced by email.

JHU is run by its faculty, not by bureaucrats, so requirements are rarely written in stone. If you have good reasons, you can petition the full CS faculty for an exception. Such petitions should be submitted in writing to the department chair. They will be considered at the next possible faculty meeting, or forwarded to the Graduate Board in the case of a university-level requirement. Note that deadlines will only be extended in unusual circumstances, such as serious medical problems or a change of advisor.

(For policies that originate above the department level, see the Whiting School of Engineering's graduate policies and procedures and the JHU Graduate Board's forms and regulations. The most important of those policies are explained on this page as well.)

Overview

Our Ph.D. program takes about 5 years, though the duration varies from student to student. Here is the basic timetable of requirements:

Years 1-2 ("qualifying requirements")	8 courses 2 research projects
Year 3	Graduate Board Oral Exam (GBO) First meeting with thesis committee
Years 4 through *n*-1	Annual meetings with thesis committee
Year *n*	Departmental seminar Thesis defense

These requirements are discussed below. The schedule is designed to help you keep moving along toward the Ph.D. You are expected to stick to it. In particular, you must not delay the third-year requirements, even if you wish you were better prepared for them.

Note that the Ph.D. qualifying requirements are a slightly stricter version of the M.S.E. requirements. Once you complete the courses and your first qualifying project, you are therefore entitled to an M.S.E. degree from JHU (upon request). Once you complete your second qualifying project and the GBO, you become a dissertation student and will get a small increase in stipend.

If you transfer into the Ph.D. program from the master's program, then the deadlines are ordinarily set as if you had been in the Ph.D. program all along (unless your advisor recommends an extension at the time of transfer).

If you spend one or more semesters as a part-time student, then the deadlines are extended accordingly, but you must still pass the qualifying requirements and the GBO within 4 calendar years of entering the program.

Important People

As a Ph.D. student, you will get to know many of the faculty. However, you will have special relationships with the following people:

- **Your advisor**'s job is to help you become a successful member of the academic community. He or she will guide your course selections and your research, give you career advice, and tell you when you are ready to defend your thesis. Most advisors also offer funding to their students, contingent on research productivity.

  A faculty advisor will be assigned to you when you are accepted into the Ph.D. program. Most students keep their advisors until they graduate, but you may change advisors at any time. Any consenting JHU CS professor may serve as your advisor, including those with secondary, joint, or research-professor appointments in the Department of Computer Science. (Column D of this table shows more precisely who may serve as a thesis advisor or co-advisor at JHU.)

- **Your thesis committee**'s main job is to decide when to accept your Ph.D. thesis. Obviously, it's wise to keep them informed and seek their counsel while you are researching and writing the thesis. You will probably also approach them for letters of recommendation as you are finishing.

  You must choose your thesis committee by the end of the third year (and as soon as possible after your GBO Exam), so that you can meet with them annually. The committee is chosen in consultation with your advisor and must include:
  1. your advisor;
  2. another member of the JHU CS faculty, who must have a primary, tenure-track appointment in the JHU CS department if your advisor does not;
  3. one or more other committee members with Ph.D. degrees. You are strongly encouraged to include someone from outside the department or university, to get the benefit of an outside perspective and to increase your work's visibility.

  In other words, you need at least 3 Ph.D.'s, at least 2 CS faculty members (including your advisor), and at least 1 core CS faculty member.

  Your committee members must agree to serve. In unusual circumstances you may change the membership of the committee, again in consultation with your advisor.

- **The graduate program coordinator,** Cathy Thornton, can help you with all kinds of administrative and financial matters.

- **The graduate program chair,** currently Prof. Jason Eisner, oversees the CS graduate program and CS graduate student life generally. If you feel you need to talk to someone outside your committee, confidentially or otherwise, try the graduate program chair (or the department chair). The graduate program chair also welcomes more general questions, comments, and concerns.

Department Seminars

You'll attend the CS department seminars throughout your degree here. These seminars are research talks by guest speakers. The usual time is 10:30 on Thursday or Friday.

Virtually every CS department in the country has a seminar series like this. That is how CS grad students and faculty keep up to date with developments in other areas of computer science. Knowing what is going on outside your narrow area of CS will enable you to teach, to draw new connections in your research, to converse knowledgeably during job interviews, to write and review grant proposals, and so forth.

To emphasize the importance of the seminar series in your education, the faculty has given it a course number. You are required to register for 600.601 every fall and 600.602 every spring. These courses are graded pass/fail based solely on seminar attendance. Grading is done on the honor system, so please be honorable -- as well as courteous to our guest speakers -- by showing up for most of the seminars (at least 2/3).

Years 1-2: Coursework

Coursework will help you educate yourself in your research area and in CS more generally. You may take or audit courses as long as you are here, including courses in other departments. A few graduate courses are offered during the summer.

In addition to the department seminar (600.601-602), you must take 8 graduate courses within your first two years. These must include at least 6 core CS courses -- two each from the Analysis, Applications, and Systems areas. The other 2 may be from CS or a related department.

Some students prefer to get the 8-course requirement out of the way in the first year. However, 4 graduate courses per semester leaves little time for research and teaching. So other students prefer to spread the coursework out over three or four semesters. Your decision will depend on your funding situation, your personal preference, and your advisor's recommendation.

Every semester, your advisor must approve and sign your course registration. This continues to be the case after the first two years.

Other "course" requirements:

- Advanced students should register for "Dissertation Research" (600.801-802) in semesters where they are not taking any regular courses.
- During your degree, you must register every semester for "Computer Science Seminar" (600.601-602). If this conflicts with another course, please contact Cathy Thornton for a waiver.
- All doctoral students (and certain master's students) are required to take the mini-course Responsible Conduct of Research (360.625), which lasts only 8.5 hours and is offered every summer, fall, intersession, and spring. You are expected to complete the course by the end of the first year. Failure to do so before the start of the fourth semester may result in a loss of funding.

How do I know if a CS course can be used as one of the 8 graduate courses? The eligible CS courses are those courses numbered 400 and above. Note that 400-level CS courses are aimed at a mixed grad/undergrad audience, whereas 600-level CS courses are specialized grad seminars. The rarely used "Graduate Research" (600.701-702) and "Independent Study" (600.809-810) may be taken for graduate

credit and a letter grade, under a faculty member's supervision. Courses do not count unless they are taken for a grade; thus you can't count pass/fail seminars (most 700-level courses) or the required department seminar series (600.601-602). (Exception: 600.464/664 does count.) Also, courses are ordinarily 3 credits; a 1-credit course counts as only 1/3 of a course.

How do I know if a non-CS course can be used as one of the 8 graduate courses? Any graduate course offered by a full-time JHU program is eligible *with advisor approval.* Your advisor must agree that the course is relevant to your degree -- either to computer science generally, or to your specific program of study and research. Graduate level courses are those numbered 600 and above, and in some departments (including AMS), those numbered 400 and above.

How do I know if a course can be used as one of the 6 core CS courses, specifically to fulfill an Analysis, Applications, or Systems requirement? Here is the official list of eligible CS and non-CS courses. For CS courses, the designations are also given in the course catalog. Non-CS courses are listed only if they have substantial CS content; moreover, *at most 1* non-CS course from this list can be counted toward the total of 6 core courses, and your advisor must approve. The list may be extended by the faculty from time to time at student request; such changes require a faculty vote.

Do I have to do well in the courses? You need at least a C- for a course to count, and your average grade for the 8 courses must be at least B+. What you learn will also help you in your GBO Exam, your research, and your future career. But ultimately, the world will judge you on your research, not your grades.

Can I fulfill any of these requirements using graduate courses taken elsewhere? Yes, if the courses have not been counted toward an undergraduate degree. They must be of comparable difficulty and appropriate for the requirements in question (e.g., Analysis/Applications/Systems), as attested by a syllabus, problem sets, or other course materials. You may apply up to 2 appropriate non-JHU courses toward the course requirements, with advisor approval. If you are willing to forego JHU's MSE degree (typically because you already earned a master's elsewhere), then you may apply more than 2 appropriate non-JHU courses toward the Ph.D. requirements, with the approval of the graduate program chair; this may include up to 4 appropriate courses from JHU's EP programs. In this case (where you reduce your coursework below 6 courses and forego the MSE degree), you may be asked to complete the other Ph.D. requirements sooner.

Years 1-2: Qualifying Projects

The Ph.D. degree is primarily a research degree, of which coursework is merely the foundation. Our program quickly gets you involved in research. From the JHU catalog:

> A student must complete two projects, each under the supervision and with the written agreement of a different faculty member in the Department of Computer Science. Upon conclusion of each project, the student must write a "Project Report" describing the project in detail. This report will be a public document and will be kept on file in the department office.
>
> The supervising faculty member must approve the project report. Departmental approval of a given project will be determined collectively by the faculty of the Department of Computer Science following the spring semester of each academic year. A factor taken into account in the departmental review of a project is the stated willingness of the supervising faculty member to enter the initial stages of a Ph.D. research advisor/advisee relationship with the student.
>
> Students have at most two years to satisfy the project component of the Ph.D. qualifying

requirements.

This requirement is essentially a chance to try out two prospective advisors -- and for them to try you out. It is wise to establish a comfortable working relationship before you embark on a long thesis project. If you have already settled on an advisor, then the second project could be a way to develop skills in some other area of computer science.

The requirement is also an opportunity for you to write some publishable research papers. In many subfields of CS, new Ph.D.s looking for jobs are expected to have published several papers already. This is an excellent chance for you to get started.

Even if the work does not immediately lead to a published paper -- for example, it is a coding project intended to enable *future* research -- you must still write it up as a project report. This ensures that you get some relatively early feedback about your writing.

It is your job to find faculty members who are willing to supervise you on projects of mutual interest. Usually you should take someone's graduate course before trying to do research with him or her. The idea for a project may come from you or from the faculty member. Note that faculty members may have varying ideas about the appropriate topic, scope and duration of a project, so you should discuss this at the start. If a qualifying project builds on a course project, the work done for course credit should not be double-counted.

Year 3: The GBO Exam

In your third year, you will face a committee of 5 professors who will evaluate your readiness to do Ph.D. research. This Graduate Board Oral Examination (GBO) is a University examination, required of all doctoral students at JHU. (The Graduate Board is the committee that oversees all graduate programs at Hopkins.)

(Also in your third year, you must take the in-person mini-course AS.360.625 Responsible Conduct of Research. This is under 10 hours and is offered during the summer, fall, intersession, and spring sessions.)

GBO Preliminary Research Proposal

In our department's tradition, the center of the GBO exam is a Preliminary Research Proposal that you write and present. This does not have to be a fully developed thesis proposal (although it could be, if you have progressed quickly). It should at least motivate some interesting research problem in the context of previous work, and sketch your possible approaches to solving it. Preliminary results are helpful but are *not* required.

Writing the proposal should be useful for you, and it will typically develop into the thesis topic. However, it is not a commitment to a topic. Its purpose is simply to focus the GBO exam. You must distribute it to all GBO examiners at least 2 weeks before the GBO. 8-10 pages is sufficient.

GBO Format

The GBO exam format is closed-door and rarely exceeds 2 hours. You will begin by presenting your Preliminary Research Proposal, and then the examiners are free to ask *any questions they want.* The department prefers that examiners focus on your readiness to do original research in the area of the

Preliminary Research Proposal. We hope that their questions will focus on the technical substance of the proposal, your ability to discuss the broad area with clarity, flexibility and maturity, and your knowledge of subjects that are likely to come into your work. However, the examiners are not bound by our requests and may assess you in any way they choose. You are therefore advised to discuss expectations with them before the exam, if they are willing.

GBO Examiners

The department will ask your advisor to suggest some reasonable examiners (see below). It is not proper for you to choose your own examiners, though your advisor may discuss with you.

The committee will consist of least 3 inside and 2 outside examiners. Your advisor counts as an inside examiner; so do all faculty with *primary* appointments in JHU CS. Everyone else counts as an outside examiner. Outside examiners are intended to contribute valuable perspectives, and also to ensure that the department doesn't let its standards slip. At least one of the outside examiners must be an Associate, Full, or Emeritus Professor; the most senior outside examiner will serve as chair.

Usually, examiners must be tenure-track JHU faculty. However, the Graduate Board *can* approve scholars from outside JHU, or research faculty at JHU. The department must petition the Graduate Board 4 weeks in advance to authorize such persons. Authorization to serve on GBO committees lasts for 5 years.

It can be tricky to find outside examiners who know enough about your research area to ask useful questions. Your advisor may nominate professors of non-CS courses you've taken -- then at least you have one topic in common. However, do not feel that you have to take irrelevant courses simply to collect GBO examiners, especially since CS faculty from nearby universities can be approved as outside examiners.

GBO Outcomes

Possible exam outcomes are described here. The most common ones are unconditional pass and conditional pass. In a conditional pass, the committee will require you to remedy some weakness in your preparation, e.g., by earning an A- or better in a particular course by a particular date.

Scheduling the GBO

It is the department's job -- not yours! -- to select your GBO committee and schedule the GBO. At least a month before you are to take the GBO (i.e., during your third year), you or your advisor should inform the CS graduate program coordinator, Cathy Thornton.

The hardest part of the GBO is finding an appropriate committee of 5 faculty examiners who are all free at the same time as you are. Fortunately, this is not your responsibility. It is handled by the department (i.e., Cathy together with the graduate program chair, Prof. Eisner).

Cathy will allow your advisor to suggest some appropriate examiners, and your advisor may in turn discuss this with you. In particular, you and your advisor should predict who will be on your thesis committee so that those faculty can be included on your GBO committee if possible.

Concretely, your advisor should send Cathy:

- The names, ranks, and email addresses of at least 3 possible inside members *in addition to* himself/herself. (This includes an extra inside member, to be approved as an alternate in case someone cancels or doesn't show up.)

- The names, ranks, and email addresses of at least 3 possible outside members. (This includes an extra outside member, to be approved as an alternate.) At least two of the outside members must be Associate, Full, or Emeritus Professors, so that someone can serve as chair.

- If any of the above is not a tenure-track JHU faculty member, then your advisor should also send Cathy (1) that person's full CV, (2) a one-page summary of *your* research, and (3) an explanation of why that person's expertise is needed at your GBO or on your thesis committee. The department will combine these into a letter petitioning the Graduate Board for approval. (See here for details.) Note that approval takes 4 weeks. Of course, this is unnecessary if the examiner is already approved.

Cathy will ask for your availability so that she can begin scheduling the exam. The *department* will then nominate a panel of examiners in accordance with their availability, JHU regulations, and your advisor's suggestions. Remember that *you* do not pick the examiners, and under no circumstances should you offend the Graduate Board by filling out the GBO form yourself. Cathy sends this form to the Graduate Board for their approval, three weeks before the exam.

Once the exam is scheduled, Cathy will tell you who the examiners are so that you can send them your Preliminary Research Proposal.

Years 3, 4 ...: Progress Reviews

You are required to meet formally with your thesis committee for a progress review at least once in each year, starting in the third year. Your annual progress letter from the department will be based on this meeting.

Your particular committee may also choose to set other requirements, including other meetings. A common requirement is that you write, present, and perhaps revise a thesis proposal -- an exercise that helps you focus your research and calibrate your expectations with the committee's.

It's often convenient to combine the third-year progress review with the GBO. The thesis committee can attend the GBO to hear your Preliminary Research Proposal, and then remain after the end of the GBO for additional discussion with you. This is straightforward to arrange when your thesis committee is a subset of your GBO committee. (Remember, the Graduate Board can authorize your non-JHU thesis committee members to serve as GBO examiners.) But even if some members of the thesis committee are not GBO examiners, they can still attend the GBO silently with permission of the GBO committee chair.

Final Year: Your Departmental Seminar

Sometime between your GBO and thesis defense, you must present your thesis work to the department in a 1-hour talk. This is primarily for the department's benefit -- everyone deserves to find out what you've been working on all those years.

Note: Some students use this requirement as a way to practice their job talk. Others use it as the first hour of their thesis defense.

Final Year: Thesis, Thesis Defense, and Revisions

The Ph.D. thesis, or dissertation, is the signal achievement of the Ph.D. degree. It is a large, careful, and substantive piece of of original work. Most computer science dissertations are 150-200 pages long, with hundreds of bibliographic references, and systematically investigate a set of ideas.

Your dissertation is presumably not the last piece of research you will ever publish, or even the most important. However, it may be one of the largest. Writing this document is a satisfying way to wrap up your graduate experience, but is itself a considerable creative act requiring plenty of time. You'll want to synthesize and explain several years of work (a process that may lead to new insights), and fill in the gaps.

Your advisor will help you decide when your thesis is essentially finished and ready to defend. You must give the thesis to your committee members at least 2 weeks before your scheduled defense date (and preferably earlier), so that they have time to read it carefully. Your defense date must also be publicly announced to the department.

The thesis defense is a public event, usually consisting of a 1-hour talk followed by questions from the committee and other audience members. Following the defense, the committee will decide what changes are required before they will sign off on the thesis.

Thesis committees almost always ask for changes, ranging from expository improvements to substantial further research. You can reduce this workload somewhat by consulting your committee frequently before the defense. But even so, you should plan for a month or more of hard work after the defense.

Your dissertation will be submitted to the JHU library and must follow certain formatting guidelines.

Time management can be tricky in the final year of the Ph.D. You may be applying and interviewing for jobs as you try to finish the research and write the thesis. And everything will take longer than you expect. So make sure to leave lots of slack in your schedule.

Feedback

Throughout your degree, you will receive feedback on what you are doing well and what you should try to improve. You will get the usual grades and other feedback on your coursework. Meetings with your research advisors and thesis committee give you personal guidance and will surely include feedback on your research, technical knowledge and skills, writing, speaking, teaching, work habits, and so on. Having a frank, open, and friendly relationship with your advisor is very important: it is how you learn how to become a full member of the academic community.

As a Ph.D. student in the department, you will receive a review letter each summer that is jointly written by the department and your advisor. The letter will review your accomplishments and will offer criticism and personal advice as appropriate, as well as reminding you of upcoming requirements.

To help the department write the annual review letter, you will first be asked to write a self-review in which you describe what you have done over the past year, offer your plans for the next year, assess your own strengths and weaknesses, and make suggestions to your advisor and the department.

If you are not in good standing with respect to the degree requirements, your annual review letter will be negative. Beyond the review letters, the department occasionally sends academic probation letters. A

graduate student may be placed on academic probation if they have failed to meet minimum academic requirements (including adequate research progress toward qualifying projects or a dissertation), or failed to meet the requirements of their university funding (research assistantship or teaching assistantship). Placing a student on probation involves a formal meeting and a letter with a deadline, detailing the corrective measures necessary to remain in the program or to retain funding. The department follows the general academic probation policy for the Whiting School of Engineering.

A Note on Funding

Ph.D. funding at JHU is pretty much the same as it is at other good CS departments in this country. No one is obliged to agree to fund you. But practically all of our Ph.D. students do receive funding for either 9 or 12 months per year.

Most students spend their first year or two funded by a teaching assistantship from the department (TA funding). Subsequently, students usually receive funding from their advisor in the form of a research assistantship (RA funding).

TA and RA funding are contingent on satisfactory progress toward the degree. Also, they may come with some strings attached. No matter how brilliant your research is, the department can't give you TA funding if you don't teach, and your advisor can't legally give you RA funding from a federal grant unless a reasonable amount of your work is related to the grant topic.

There are also other ways to get money:

- You may be able to win your own funding from some sort of fellowship. For example, if you are a U.S. citizen and have completed less than 12 months of full-time graduate study, you can apply for an NSF Graduate Research Fellowship.
- If you can find a summer job doing CS research in industry, that can be good experience and pay well. (Although it might interrupt your progress toward graduation.) Of course, you cannot receive summer RA funding if you are also working a full-time job elsewhere.
- The department hires course assistants (CAs) at an hourly rate. This could be a good way to make some money if you were not otherwise funded.

In general, you should discuss your plans with your advisor.

A Note on Teaching Experience

If you enjoy teaching and plan to become an academic, then you should aim to get some teaching experience during grad school.

You might ask a faculty member if you can give a couple of his or her lectures (especially if you are the TA). Be sure to ask for feedback. You could also help develop course materials, such as homework assignments.

More significantly, our department is willing to let Ph.D. students design and teach their own short courses. A short course is a 1-credit course that meets for a total of 12 hours (1 hour per week all semester, or 3 hours per week for 4 weeks). If you are interested, you should get a faculty sponsor and develop a course proposal for approval by the department chair. This should be done by the middle of the

previous semester so that the course can be scheduled and listed in the course catalog.

Comments or questions on this page? Contact these folks.

EXHIBIT S

Russ Taylor <rht@jhu.edu>
To: Greg Hager <hager@cs.jhu.edu>
Re: FYI - papers based on my thesis

December 9, 2010 8:31 PM

Thanks again.

On 12/9/10 5:00 PM, "Greg Hager" <hager@cs.jhu.edu> wrote:

> Thanks -- I just did a quick scan -- a few quick things I didn't realize when we talked -- namely both papers cite Rajesh, and the IROS paper in particular cites his thesis, so I am at least comforted by that -- I thought you meant we had not cited him at all!
>
> Here is the relevant discussion in the IROS paper: (6 is Rajesh's thesis, but the discussion seems to mix the results of 5 and 6 up at one point).
>
> The work pursed in this paper builds upon the research presented in [5] and [6]. The former studies augmented surgical manipulation tasks in order to create an environ- ment that makes it possible to easily and safely specify a set of control primitives (basic control modules) necessary for a number of different surgical procedures. The latter is concerned with the issue of providing the appropriate assistance to the users by recognizing their actions using continuous Hidden Markov Models.
>
> Based on these, we are interested in building a system that provides an optimized augmentation based on the context of the task. Compared to the approach presented in [6], we propose an approach to task level modeling con- sidering both unconstrained and constrained robot motion. By using a predefined modeling schema and a number of basic steps, it is easy for the user to model a variety of complex tasks. By using the proposed framework, the ideas in [5] can now easily be integrated in the system to build graphs for new tasks.
>
> The figure is more troublesome. It's clearly different -- the arrows go different places -- but its the same enough to wonder why. That I could only find out from Dani as she would have produced it.
>
> I'll look a bit more into it.
>
> G
>
> Gregory D. Hager, Professor
> Department of Computer Science
> The Johns Hopkins University
> 3400 N. Charles St.
> Baltimore, MD 21218
>
> Tel: 410-516-5521
> Fax: 410-516-4410
> Email: hager@cs.jhu.edu
> Office: 121 CSEB
> WWW: http://cs.jhu.edu/~hager
> Calendar: http://www.cs.jhu.edu/~hager/calendar.html
>
> On Dec 9, 2010, at 4:25 PM, Russ Taylor wrote:
>
>> Here are the papers we talked about
>> ----- Forwarded Message
>> From: Rajesh Kumar <rajesh@jhu.edu>
>> Reply-To: Rajesh Kumar <rajesh@jhu.edu>
>> Date: Thu, 9 Dec 2010 11:29:55 -0500

DEPOSITION EXHIBIT
PENGAD 800-631-6989
6
Taylor 10/15/13

To: Russell Taylor <rht@jhu.edu>
Subject: FYI - papers based on my thesis

FYI. In particular the journal article (e.g. Figure 6), and Figure 5.13 of my thesis.

--
Rajesh Kumar, PhD
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http://www.cs.jhu.edu/~rajesh

----- End of Forwarded Message

<kragic_iros03.pdf><The International Journal of Robotics Research-2005-Kragic-731-41.pdf><thesis-2001.pdf>

EXHIBIT T

Vengraitis

UNITED STATES DISTRICT COURT
FOR THE DISTRICT OF NEW JERSEY
-----------------------------x
RAJESH KUMAR,

Plaintiff,

v. No. 2:12-cv-06870-KSH-PS

THE INSTITUTE OF ELECTRICAL
AND ELECTRONICS ENGINEERS, INC.,
a New York corporation,

Defendant.
-----------------------------x

30(b)(6) Deposition of The Institute of Electrical and Electronics Engineers, Inc.

by

ANTHONY B. VENGRAITIS

New York, New York

Wednesday, November 13, 2013

Reported by: Steven Neil Cohen, RPR

Job No. 39489

Vengraitis

November 13, 2013

9:12 a.m.

Deposition of ANTHONY B. VENGRAITIS, taken by Plaintiff, pursuant to notice, at the offices of Dorsey & Whitney, LLP, 51 West 52nd Street, New York, New York, before Steven Neil Cohen, a Registered Professional Reporter and Notary Public of the State of New York.

Vengraitis

APPEARANCES

DAVIS WRIGHT TREMAINE LLP
1201 Third Avenue
Suite 2200
Seattle, Washington 98101
Attorneys for Plaintiff
BY: ERIC M. STAHL, ESQ.

DORSEY & WHITNEY LLP
51 West 52nd Street
New York, New York 10019-6119
Attorneys for Defendant
BY: BRUCE R. EWING, ESQ.

ALSO PRESENT:
Jonathan S. Wiggins, Esq.

Vengraitis

IT IS HEREBY STIPULATED AND AGREED, by and between counsel for the respective parties hereto, that the sealing and filing of the within deposition be waived; that such deposition may be signed and sworn to before any officer authorized to administer an oath; that all objections, except as to form are reserved to the time of trial.

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Vengraitis
MR. STAHL: Mark this as IEEE Exhibit 1.
(Notice of Deposition was marked IEEE Exhibit 1 for identification)
ANTHONY B. VENGRAITIS, called as a witness by the Plaintiff, having been duly sworn, testified as follows:
EXAMINATION
BY MR. STAHL:
Q. Good morning, Mr. Vengraitis.
A. Good morning.
Q. I am Eric Stahl. We met a moment ago. I am counsel for Dr. Rajesh Kumar in this lawsuit.
I understand you are here -- you understand you are here on behalf of the defendant which we will refer to at IEEE to testify on certain topics on behalf of the corporation?
A. Yes.
Q. Have you had your deposition taken before?
A. No.
Q. It is important that you answer

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verbally because the court reporter is taking a verbatim transcript so say yes or no as opposed to nodding or uh-huh.
A. Will do.
Q. You understand you have taken an oath under penalty of perjury to answer my questions truthfully?
A. Yes.
Q. You have Exhibit 1 which the court reporter had previously marked in front of you?
A. Yes, I do.
Q. This is a notice of deposition under Rule 30(b)(6) for IEEE.
Do you mind turning to the page labeled Exhibit A?
A. Okay.
Q. This is the list of topics for today's deposition. My understanding and please confirm if you will is that you will be testifying on topic 1?
A. Yes.
Q. Topic 5?
A. Yes.

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Vengraitis
Q. Topic 7 I understand both you and Mr. Durniak -- did I say that right?
A. Yes.
Q. Topic 7 both you and Mr. Durniak will be testifying about?
A. I think so, yes.
Q. Also topics 8 and 10?
A. Yes.
Q. Topic 11 as well?
A. Yes.
Q. And I understand topic 13 is another one that you will be testifying to along with Mr. Durniak?
A. Yes.
Q. Okay. And topics 14, 15, 16 are not yours, they are Mr. Durniak's, correct?
A. I believe so, yes.
MR. EWING: It is set forth in a letter that we sent you so whatever the letter says is how they have been allocated.
MR. STAHL: Okay. I am just trying to confirm the letter. Thank you.

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Vengraitis
BY MR. STAHL:
Q. What is your position with IEEE?
A. I am intellectual property rights specialist.
Q. What do you do?
A. I work in the intellectual property rights office. Our office manages copyrights, some registration of the same, we also do -- handle plagiarism complaints.

We provide other services to the volunteers who work in publications in terms of copyright advice, related IEEE policy and author misconduct as well.
Q. So it is part of protecting IEEE's copyrights?
A. Yes.
Q. Okay. How long have you been in that position?
A. Since May 2005 so about eight-plus years.
Q. What is your educational background?
A. I have a Bachelors of Arts in

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Q. How do you know that there were printed versions at one point?
A. I don't know for a fact that there were printed copies but I assume that most conferences in that time period distributed, published, or printed proceedings to the attendees. That was a standard way of distributing that information to attendees.
Q. But typically at IROS conferences in this period everybody who showed up would get a copy of the publications published in connection with the conference?
MR. EWING: Objection to form.
You can answer the question.
THE WITNESS: Typically, yes.
BY MR. STAHL:
Q. Do you know how many people attended the 2003 IROS conference?
A. I, I don't know for sure.
Q. Can you give me a range?
MR. EWING: Objection.
Speculative.
You can answer.
THE WITNESS: It may be in the

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range of 100 attendees.
BY MR. STAHL:
Q. Okay. Is there a way to find out from the records how many people attended?
A. I think there would be a way to find out. I can look and see if there is a record of the conference in our database somewhere and it might show how many attended.
MR. STAHL: For the record and I will follow up with a request in writing, if there is a way to find out that information exists I would like to know how many people.
MR. EWING: We will take it under advisement.
MR. STAHL: Thank you.
Exhibit 3.
(Copy of the Kragic and Hager article was marked IEEE Exhibit 3 for identification)
BY MR. STAHL:
Q. Exhibit 3 is a copy of the Kragic and Hager article that IEEE produced to us

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in this litigation.
You see it has the copyright notice for IEEE on the bottom?
A. Yes, I do.
Q. Do you know where -- what the source of this version of the article was?
A. I believe it is in an electronic version of the article that we keep in IEEE Xplore.
Q. This is not a copy of a printout or I am sorry, a copy of the printed version of the article?
A. I don't know. It may have been a scanned copy when they were creating this particular conference's files for IEEE Xplore they may have scanned a copy but there may have been an electronic version of it available as well. They may have just used that.
Q. In the footer of the document next to the copyright notice there is a reference to $17.
Do you see that?
A. Yes.

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Q. What does that refer to?
A. I think that is the CCC charge that -- it is the Copyright Clearance Center and they, they have a fee for reproducing or photocopying of documents and so if someone were to want to know how much it would cost to reproduce a -- or to photocopy and to distribute a paper they would know that they would be charged $17 by the Copyright Clearance Center as a permission fee.
Q. Okay. So the Copyright Clearance Center distributes the article at this point?
A. No. We just provide that information as a service to anyone who would want to possibly photocopy and distribute to allow them to -- to know how much it will cost them.
Q. All right.
Just so I am clear. So if I, setting aside any subscription-based access which we will talk about later today if I wanted to get a copy of this article, the Hager and Kragic article are you saying that

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a paper after it has been published does she or doesn't she have an obligation to correct it promptly?
A. They would have an obligation to correct it but there would be means of correcting it such as submitting an addendum or a verbalized paper.
Q. What does "promptly" mean in this context?
A. I don't know. I don't know if there is any specific to that.
It is just quickly but I don't know if there is any specific time.
Q. On the next page, 83 of Exhibit 7.7 state, "IEEE defines plagiarism as the use of someone else's prior ideas, processes, results or words without explicitly acknowledging the original author and source."
Is that a correct statement of how IEEE defines plagiarism?
A. Yes.
Q. Further in these guidelines IEEE categorizes plagiarism by five different

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levels, right?
A. Yes.
Q. They depend on the nature of the copying and they have very specific criteria?
A. Yes.
Q. Turn to page 91 please.
Section 8.2.4. Are you with me?
A. Yes.
Q. Is this the section 8.2.4 the IEEE procedure for handling allegations of plagiarism and other types of misconduct?
A. Yes.
Q. Am I correct this policy covers more than just plagiarism, right?
A. Yes. It can be used for other types of author misconduct.
Q. Okay. So if someone has a complaint about accuracy or completeness somewhere in 8.2.4 there is a process for that, right?
A. Yes.
Q. Okay. And it covers more than just complaints against authors as well. If

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someone alleges an editor has a bias that is covered in here someplace as well?
A. There may be that as well. I think it focuses mostly on author misconduct.
Q. Okay. Well, if the complaint is one of plagiarism against an author am I correct that the correct policy is 8.2.4B on page 93?
A. Yes.
Q. Walk me through the process of what is supposed to happen when IEEE receives an allegation of plagiarism against an author for an article or paper that has been published.
A. Well, the initial step is to notify the organizational unit, the society or section that is responsible for that publication.
We find a person or a publication officer or the editor who may have been -- say it is a journal. We can contact the editor in chief.
The author is -- the offending

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author is the plagiarist or alleged plagiarist is contacted to allow that person to respond to the complaint.
Once that information is received the society chair or the editor-in-chief forms an ad hoc committee making sure that these people are free of conflict of interest and asks them to review the allegations, the papers involved, the response from the accused author.
And they base their decision on the plagiarism guidelines that are in the PSPB ops manual, operations manual, that assigns it a specific level and the corresponding corrective actions that would go with it.
Q. Okay. Would you agree that the appointment of an ad hoc committee is not discretionary, it is mandatory under the policies?
A. It should be mandatory, yes.
Q. Take a look at, on page 93, .B3, it says, "In considering the allegation the responsible person shall appoint an

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independent ad hoc committee of experts in the topic to confidentially investigate and make a recommendation on the allegation to the responsible person."
It says -- so it says, "The responsible person shall appoint an ad hoc committee." Yes?
A. Yes.
Q. So you would agree it is a mandatory step in the process?
MR. EWING: Objection to form.
THE WITNESS: Yes.
BY MR. STAHL:
Q. In the case of a conference publication like the IROS proceedings who is the responsible person?
A. The sponsor of the event who it was the Robotics and Automation Society and in this case we contacted the publication chair who was Alessandro De Luca.
Q. In the case of Dr. Kumar's complaint?
A. Yes.
Q. Okay. Because in 2012 -- is it

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Dr. De Luca?
A. It might be Professor De Luca.
Q. In 2012 Professor De Luca was the chair of the IROS conference?
A. No. He was the publication -- I am sorry. The vice -- I may have said publication chair. The vice president of publications at Robotics and Automation.
Q. Which is responsible for the IROS?
A. Right. They were the sponsor of the IROS conference.
Q. Turn to page 95. Page 95 through page 100, am I correct these are the five levels of plagiarism as IEEE defines them?
A. Yes.
Q. The definitions and the remedies for each level of plagiarism are as they are defined in this written manual?
A. Yes.
Q. There is not some separate unwritten understanding of what constitutes plagiarism within IEEE?
A. No. Although these are plagiarism guidelines so societies have the ability to

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follow these guidelines but if they feel there are additional corrective actions that they would like to use they can bring that matter to the PSPB chair who is the final -- has the final decision on any upper level plagiarism case and also can approve these if he feels these are warranted.
Q. In the case of RAS or IROS are there any such additional guidelines or plagiarism definitions?
A. Not that I am aware of.
Q. Okay. There is not a separate set of guidelines for IEEE generally beyond what is on these pages 95 through 100?
A. No.
Q. So is it the case that IEEE won't find something to be plagiarism unless it fits the specific definitions of one or more of these five levels?
A. That is correct.
Q. How many plagiarism investigations have you participated in in your time at IEEE?
A. There have been probably somewhere

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in the neighborhood of 600.
Q. How many a year does IEEE --
A. It has been escalating but in the last two years we have had in the neighborhood of about 200 each year.
Q. Okay. That is across all IEEE publications?
A. Yes.
Q. How often is a complaint or allegation of plagiarism sustained?
A. "Sustained" meaning?
Q. Meaning some level of plagiarism is found.
A. I would say the majority of, almost all.
Q. Almost all of the plagiarism complaints that IEEE gets are found to be valid?
A. I would say probably there may be one or two per year that aren't found to be valid.
Q. This 200 or so complaints a year that you are referring to, they are all plagiarism investigations under the policy

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Vengraitis

of non-IEEE publications that are plagiarizing overseas.

We find a lot of publications from China and India that are having a lot of problems with plagiarism and we manage those as well.

Q. I see.

A. We receive those.

Q. Okay. Well, I had asked you before how many plagiarism complaints IEEE handles in a given year. Let me put a finer point on it then.

How many complaints does IEEE handle alleging that an IEEE publication contains plagiarized material?

A. I don't know a breakdown between -- say the 200 that we have per year what percentage of that is IEEE plagiarized -- plagiarizing or an incident with an IEEE paper. I don't know. I don't know an exact number.

Q. Can you give me a rough breakdown?

MR. EWING: Objection. Asked and answered.

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THE WITNESS: I really couldn't say for sure.

I would guess that at least half are involving IEEE papers that have plagiarism.

BY MR. STAHL:

Q. Okay. Of the complaints that your office handles involving IEEE articles that are alleged to contain plagiarized material how often are those complaints found to be valid?

A. Nearly all the time.

Q. You are aware that in January of 2012 Dr. Kumar complained to IEEE that the IROS article plagiarized his thesis?

A. Yes.

Q. How did that come to your attention?

A. It was a complaint that was forwarded to our department. I don't recall specifically who forwarded the complaint but then it was brought to my attention by Bill Hagen.

MR. STAHL: Exhibit 8.

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(E-mail of January 4, 2012 with other e-mails was marked IEEE Exhibit 8 for identification)

BY MR. STAHL:

Q. Exhibit 8, have you seen this before?

A. Yes.

Q. Is this the first you heard of Dr. Kumar's complaint to IEEE?

A. Yes.

Q. So on January 4, 2012 Dr. Kumar sent an e-mail to ethics@IEEE.org with the message contained on the second page of Exhibit 8.

What is that e-mail address?

A. Ethics@IEEE.org.

Q. Yes.

A. It is an e-mail alias. I don't know who specifically receives it but there is someone in IEEE, probably a staff member who receives these e-mails and forwards them to whomever would need to handle it.

Q. Okay. How did this make its way to you?

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A. I believed it originally went to Bill Hagen but then Bill Hagen directed it toward me. It looks as if -- actually it says it was forwarded by Jon Soifer.

It is even possible that John forwarded it -- or contacted Bill Hagen and then John forwarded the e-mail to me or Jon may have spoken to me on the phone. I don't recall.

Q. Where are you seeing John's name?

A. It is on the first page, three or four lines up from the top -- from the bottom where it says forwarded by Jon Soifer.

Q. And you responded to Dr. Kumar on January 5, correct?

A. Yes.

Q. That is your e-mail at the top of the page?

A. Yes.

Q. You wrote, you say, "There are discrepancies in the IJPP paper by Kragic, et al." These discrepancies -- "If these discrepancies involve copied IEEE material

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clear not just about you but about anybody associated with IEEE to your knowledge no one with IEEE received a response from Drs. Hager or Kragic?
A. I don't believe so.
Q. Point 1 of your e-mail states, "If appropriate the society will constitute an ad hoc committee of qualified individuals to examine the paper in question against the previously published papers."
What did you mean by "if appropriate"?
A. To be honest it is somewhat of a form letter but it is -- I guess it harkens back to what we said that all cases should be handled with an ad hoc committee review.
It was just the way it was worded that I guess it would allow for the possibility that a case might be handled differently if it wasn't appropriate for some reason for a society to review it.
Q. In fact, initially, IEEE did not refer this to an ad hoc committee?
A. That is correct.

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Q. You attempted to handle it solely through a review by Professor De Luca?
A. That is correct.
Q. Why was that?
A. I suppose it was because it seemed that it was a small enough case and perhaps was simple enough for one person to examine the information and to come to a quicker conclusion if there was no plagiarism involved.
If there was plagiarism involved, if the -- if Dr. De Luca believed that there was in fact plagiarism involved I would have recommended that he get an ad hoc committee to review it and determine the appropriate level.
Q. Well, you told me earlier that in response to a complaint of plagiarism the responsible person is required under IEEE's policies to appoint an ad hoc committee, right?
A. Right.
Q. There is nothing in the policies about a different process for smaller or

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simple cases, correct?
A. That is correct.
Q. Would you agree that IEEE in its initial response to Dr. Kumar's plagiarism complaint did not follow its own written policies?
A. Yes.
Q. Why?
A. I don't know other than the possibility that it was not -- the complaint didn't have merit. If it had merit -- if the VP of publications felt it did have merit I would have expressed that the procedure should be followed as outlined in the ops manual, the operations manual.
Q. But again the ops manual does not have a separate process for the responsible person to determine on his own whether or not a complaint has merit?
A. That is correct.
Q. Were you not aware of the requirement that a -- an ad hoc committee be appointed?
A. I was aware that there is language

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in the, in the policy that says that a committee shall be appointed but I did not see it as being -- I did not, I did not follow it in this case. I didn't stress this to the VP of publications.
Q. In practice does IEEE follow its written --
A. Yes.
Q. Let me finish the question.
A. Sorry.
Q. In practice does IEEE follow its written policy of appointing an ad hoc committee in response to other plagiarism complaints?
A. Yes.
Q. Was Dr. Kumar's complaint the first plagiarism complaint your office has handled where an ad hoc committee was not appointed?
A. It may not have been the first.
There may have been one or two others perhaps in my time at IEEE.
And in those cases it may have been a complaint that appeared to have no

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members or was there some other criteria for being considered for this committee?
A. I believe Dr. De Luca also wanted to find people who were familiar with the subject and with the technology involved.
Q. Okay. Do you know how he identified such people?
A. No, I don't.
Q. Is there a preexisting list of RAS members who are capable of evaluating this type of work?
A. I don't know for sure. I imagine that the robotics society does have a list of its members.
Q. Do you know if he asked anybody to serve on the committee who refused to serve?
A. I don't recall.
Q. Do you have any information at all about members who were approached but declined to be on this committee?
A. Dr. De Luca kept me copied on a number of e-mails while he was going through that process but I don't recall if he had potential members that declined.

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Q. Who would then at IEEE is aware of the identity of the committee members?
A. I was copied on some of the e-mails that I might have a record of it.
Otherwise, I believe that the PSPB chair who eventually looked at the appeal was given the identities of the ad hoc committee members to confirm their -- well, with the publication conduct committee, the body that he uses to act as his ad hoc committee, they investigated.
MR. EWING: Let me just caution the witness that as the court ordered yesterday the identities of all reviewers, ad hoc and on the appeal are not to be disclosed.
MR. STAHL: Just for the record you know I would like to ask if I were able to the names of the ad hoc committee members. There is a court order. Mr. Ewing, I presume IEEE's position has not changed on that subject.
MR. EWING: Certainly not.

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Vengraitis
BY MR. STAHL:
Q. Were the identities of the ad hoc committee members known as far as you are aware to anybody outside of your office and the publications board and the committee you just referenced?
A. I am not aware.
Q. Do you know whether all of the members of the ad hoc committee are -- have expertise in medical robotics?
A. I don't know.
MR. STAHL: Exhibit 15.
(E-mail to Professor De Luca from Anthony Vengraitis was marked IEEE Exhibit 15 for identification)
BY MR. STAHL:

REDACTED

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REDACTED

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REDACTED

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REDACTED

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REDACTED

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Q. Did Professor De Luca ever disclose to IEEE that his grad student, a Dr. Bettini preceded Dr. Kragic on the same project at Johns Hopkins?

A. I have learned that recently but I did not know that at the time.

Q. Would that have posed a conflict for Professor De Luca to participate in a plagiarism review involving research that a doctoral student he was advising was involved in?

MR. EWING: Objection to form. Assumes facts not in evidence and speculative but you can answer.

THE WITNESS: I really don't know

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that would qualify as a conflict.

BY MR. STAHL:

Q. Might it?

MR. EWING: Objection to form. Same objections.

THE WITNESS: I don't know.

BY MR. STAHL:

Q. Was IEEE aware at any time that this grad student of Professor De Luca's had co-authored articles on the same topic as the IROS article with Professor Hager?

MR. EWING: Objections to form. Same objections.

THE WITNESS: I don't know if anyone was aware of that.

BY MR. STAHL:

Q. Would that be a potential conflict?

MR. EWING: Same objections.

THE WITNESS: I can't say. I don't know.

BY MR. STAHL:

REDACTED

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REDACTED

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REDACTED

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REDACTED

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.

REDACTED

e that this is

not an example of plagiarism."

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REDACTED

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REDACTED

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REDACTED

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REDACTED

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MR. STAHL: Exhibit 20.

(Document Bates numbered RK-IEEE 0000861 was marked IEEE Exhibit 20 for identification)

BY MR. STAHL:

Q. Exhibit 20 is a document Bates numbered RK-IEEE 0000861.

I will represent to you that indicates is a document produced by Dr. Kumar in this case.

This is the ad hoc committee report as was sent to Dr. Kumar.

Point 4 now says, in the second sentence, "Even if this figure should have been acknowledged in such a way that the figure is derived from Kumar's figure we believe that this is within an allowable range as far as Kragic article refers Kumar thesis."

REDACTED

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REDACTED

levels 1 through 5.

Vengraitis
their papers but IEEE houses the papers.
Q. Can you tell me over the last three years how many subscriptions -- how many subscribers IEEE has sold that provide full Xplore access?
A. I don't know. That may be for Tony Durniak.
Q. Do you know if IEEE has ever paid any royalties on any article?
A. I don't know.
MR. STAHL: Give me one second. Off the record.
(Discussion off the record)
MR. STAHL: I don't have any further questions for this witness.
We will hold the deposition open for Mr. Durniak's section and I will state for the record I reserve the right to hold it open for issues related to PCC and other documents that we think we are entitled to but for now I will thank you for your time and let's take a break and wait for Mr. Durniak.
MR. EWING: Just for the record I

Vengraitis
have no questions of the witness.
(Time noted: 1:45 p.m.)

ANTHONY B. VENGRAITIS

Subscribed and sworn to
before me this day
of 2013.

____

Vengraitis
CERTIFICATE
STATE OF NEW YORK)
: Ss
COUNTY OF NEW YORK)
I, Steven Neil Cohen, a Registered Professional Reporter and Notary Public within and for the State of New York, do hereby certify: That ANTHONY B. VENGRAITIS, the witness whose deposition is herein before set forth, was duly sworn by me and that such deposition is a true record of the testimony given by such witness.
I further certify that I am not related to any of the parties to this action by blood or marriage and that I am in no way interested in the outcome of this matter.
I further certify that neither the deponent nor a party requested a review of the transcript pursuant to Federal Rule of Civil Procedure 30(e) before the deposition was completed.
In witness whereof, I have hereunto set my hand this 22nd day of November 2013.
Steven Neil Cohen

STEVEN NEIL COHEN, RPR

Vengraitis

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Vengraitis

DEPOSITION ERRATA SHEET

Assignment No. 39489

Case Caption: Kumar vs. IEEE

DECLARATION UNDER PENALTY OF PERJURY

I declare under PENALTY OF PERJURY that I have read the entire transcript of my Deposition taken in the captioned matter or the same has been read to me, and the same is true and accurate, save and except for changes and/or corrections, if any, as indicated by me on the DEPOSITION ERRATA SHEET hereof, with the understanding that I offer these changes as if still under oath.

____

ANTHONY B. VENGRAITIS

Subscribed and sworn to on the _______ day of __________, 2013 before me,

____

Notary Public,
in and for the State of ________________.

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ANTHONY B. VENGRAITIS

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EXHIBIT V

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EXHIBIT
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EXHIBIT W

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EXHIBIT X

Report of plagiarism case evaluation

Our judgment

This is not a case of "plagiarism".

The reasons are described in the following.

(1) Level 1 through Level 5 of Plagiarism defined by IEEE rule are supposed "without reference" or "without bibliography" or "no reference appears with the text" or "without clear delineation". However, as far as Kragic article is concerned, it refers Kumar's articles with even three related papers, while there is a fact that two references were switched by an unfortunate mistake. Furthermore, Kragic article clearly states in page 2 that "The work pursed in this paper builds upon the research in [5] and [6]", where [6] is Kumar's thesis. Due to these evidences, this is not any example of "Level 1 through Level 5 of plagiarism" defined by IEEE rule.

(2) The complaint letter repeatedly refers to the fact that the Kragic article did not go beyond the capabilities of the thesis and did no experimental evaluation. This may be evidence of a poor technical paper, but it hardly constitutes plagiarism. It also repeatedly complains that the Kragic article builds on the hardware and software that Kumar developed for his thesis. Again, building on someone else's work is not plagiarism.

(3) The complaint letter says that the Kragic primitives are "taken entirely from the thesis." There are certain things that need to happen (moving, orienting, puncturing) that all cannulation procedures would have to do. However, the method in which Kragic/Hager represent the primitives (XML vs FSM) is quite different and the use of "virtual fixtures" is quite different.

(4) The complaint letter says "Figure 1 of Kragic article-An example of basic task graph for vein cannulation-lifted from Figure 5.13 (p70) of the thesis" in page 3. Even if this figure should have been acknowledged in such a way that the figure is derived from Kumar's figure, we believe that this is within an allowable range as far as Kragic article refers Kumar thesis.

EXHIBIT Y

Durniak

UNITED STATES DISTRICT COURT
FOR THE DISTRICT OF NEW JERSEY
-----------------------------x
RAJESH KUMAR,

Plaintiff,

v. No. 2:12-cv-06870-KSH-PS

THE INSTITUTE OF ELECTRICAL
AND ELECTRONICS ENGINEERS, INC.,
a New York corporation,

Defendant.
-----------------------------x

30(b)(6) Deposition of The Institute of Electrical and Electronics Engineers, Inc.

by

ANTHONY DURNIAK

New York, New York

Wednesday, November 13, 2013

Reported by: Steven Neil Cohen, RPR

Job No. 39489

Durniak

November 13, 2013

2:12 p.m.

Deposition of ANTHONY DURNIAK, taken by Plaintiff, pursuant to notice, at the offices of Dorsey & Whitney, LLP, 51 West 52nd Street, New York, New York, before Steven Neil Cohen, a Registered Professional Reporter and Notary Public of the State of New York.

Durniak

APPEARANCES

DAVIS WRIGHT TREMAINE LLP
1201 Third Avenue
Suite 2200
Seattle, Washington 98101
Attorneys for Plaintiff
BY: ERIC M. STAHL, ESQ.

DORSEY & WHITNEY LLP
51 West 52nd Street
New York, New York 10019-6119
Attorneys for Defendant
BY: BRUCE R. EWING, ESQ.

ALSO PRESENT:
Jonathan S. Wiggins, Esq.

Durniak

IT IS HEREBY STIPULATED AND AGREED, by and between counsel for the respective parties hereto, that the sealing and filing of the within deposition be waived; that such deposition may be signed and sworn to before any officer authorized to administer an oath; that all objections, except as to form are reserved to the time of trial.

Durniak
ANTHONY DURNIAK, called as a witness by the Plaintiff, having been duly sworn, testified as follows:
EXAMINATION
BY MR. STAHL:
Q. Good afternoon, Mr. Durniak.
A. Good afternoon, Mr. Stahl.
Q. You are here to testify on certain topics that the defendant in this case which I will refer to IEEE has designated you to testify on.
You understand that?
A. Yes, I do.
Q. Have you had your deposition taken ever before?
A. No.
Q. You understand you are under oath and bound under penalty of perjury to answer my questions truthfully?
A. I certainly do.
Q. Okay. The court reporter is taking a verbatim transcript so it is important that we try not to talk over each other as we would in normal conversation,

Durniak
that you answer the questions verbally rather than nodding, for example, do you understand that?
A. I understand.
Q. Great.
The court reporter has put in front of you Exhibit 1 which is the notice of deposition for today's proceeding.
If you turn to page 4 it has a list of topics.
I just want to confirm per counsel's letter that you are here to testify on the following topics, 3 and 4, correct?
A. Yes.
Q. Seven?
A. Yes.
Q. Nine and 13 through 16?
A. Yes.
MR. STAHL: Back on the record.
BY MR. STAHL:
Q. The document you are looking at was marked earlier today as IEEE Exhibit 1.
What is your position with IEEE?

Durniak
A. I am a staff executive for publications.
Q. What do you do in that role?
A. In that role I lead the professional team that supports the publishing program of the IEEE which means I supervise the editorial production and delivery functions for our information products and services which includes our journals, magazines, conference proceedings and standards.
Q. How long have you been in that position?
A. Fifteen years.
Q. Same position for all 15 years?
A. Yes.
Q. What is your educational background?
A. I have a Bachelor's degree in electrical engineering from the City College of New York.
I have a Master's degrees in journalism from Columbia University.
Q. When did you get your bachelors?

Durniak
A. I got my bachelors in 1975.
Q. Have you held any other positions with IEEE prior to your current title?
A. No.
Q. You are aware that my client, Rajesh Kumar has raised certain complaints about an article published by IEEE?
A. I am.
Q. You are familiar with the article by Dr. Hager and Dr. Kragic that is at issue here?
A. I have seen a copy of it. I am not qualified in the field to become intimately familiar with the contents but I have seen the article, yes.
Q. Okay. But if I refer to it as the article just to be clear we are talking about the 2003 IROS article by Hager and Kragic.
A. I understand that.
Q. Okay. When did you personally first become aware that Dr. Kumar had complaints about the article?
A. As I recall I became aware of it

Durniak
A. No.
Q. Have you ever spoken to him?
A. No.
Q. E-mailed?
A. No.
Q. George Lee, do you know his affiliation, what institution he is affiliated with?
A. No. I don't know the gentleman.
MR. STAHL: Exhibit 25.
(Document Bates numbered IEEE_519 was marked IEEE Exhibit 25 for identification)
BY MR. STAHL:

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Q. Thank you for that.
Do you have any information about the decision to select this article, the Hager-Kragic article for publication that you haven't testified to?
A. No.
Q. Let's move on to a different topic.
This is topic 9, the decision to publish a correction in connection with the article.
You are aware that a notice of correction was published in connection with the Kragic-Hager article?
A. Yes, I am.
Q. Okay. We have to try not to talk over each other for the court reporter's benefit so please let me finish the question.
Who made the decision to publish that correction?
A. The decision was made by our vice president for publications based on the recommendation of our -- the investigation

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committee that had looked into this complaint.
Q. Who is the vice president you are referring to?
A. I believe at that time it was Dr. David Hodges.
Q. Dr. Hodges is not an IEEE employee?
A. Correct. He is a volunteer.
Q. Where is he affiliated?
A. He is -- right now he is retired so he is not affiliated with anyone.
Q. Was he a professor?
A. Yes, he was a professor at the University of California, Berkeley.
Q. Is he still in that position for IEEE?
A. No.
Q. When did David Hodges decide a correction not to be published?
A. I do not remember the exact date.
Q. You mentioned it was as a result of the decision of the committee that had looked into this matter. Are you referring

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to the ad hoc committee that reviewed Dr. Kumar's plagiarism complaint?
A. I am not sure whether it was the first ad hoc committee or the subsequent -- on appeal there was subsequent look at it by our Publishing Conduct Committee. I don't know which committee made that recommendation.
I just know one of those committees made the recommendation.
Q. Do you have the -- are you aware of the timing of the various investigations and appeals?
A. I don't have all the exact dates memorized but I have the rough outline, I am aware of the rough outline, yes.
Q. Okay. So you understand that the ad hoc committee investigated in the summer of 2012, issued a decision or a report in July of 2012?
A. Yes.
Q. And the -- was it the Publishing -- the PCC committee issued its decision, do you know when that was?

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A. Again, I don't remember the exact date but I know it was after the ad hoc committee.
Q. Was Mr. Hodges or Professor Hodges waiting for the ad hoc -- I am sorry. Let me restate that.
Was David Hodges waiting for the appeal process to run its course before he decided to run the correction?
A. Yes. As I said he need the investigation to run its course so that the recommendation could come forward as to what should happen.
Q. Okay. The reason I am asking is because the ad hoc completed its work in July, I believe the correction didn't appear until December of 2012. Do I have that right?
A. The correction did appear in December, correct.
Q. So was there a reason for the gap between July and December?
A. Not that I remember.
MR. STAHL: Exhibit 26.

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Durniak
(Notice of correction was marked
IEEE Exhibit 26 for identification)
BY MR. STAHL:
Q. The court reporter has handed you Exhibit 26.
Do you recognize this as the notice of correction that IEEE has published in connection with the article?
A. Yes.
Q. There is a reference here in the first sentence to -- it states, "After careful and considered review of the content of this paper by a duly constituted expert committee a correction has been deemed appropriate."
The reference to "a duly constituted expert committee," is that to the ad hoc committee?
A. It would refer to both the ad hoc committee and in this case the appeal to the Publishing Conduct Committee, PCC.
Q. Are you aware of any report or findings issued by the PCC?
A. I don't remember the exact words

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but, yes, I am aware that there is a report from them.
Q. Can you describe that report to me?
A. Not by memory. I know it is in the documents that have been presented.
Q. I have seen the decision and findings of the ad hoc committee and we have received a letter notifying us of the decision on the appeal.
Is there a separate document or report of the PCC to your knowledge?
A. I would -- there must have been -- there should be some document that came out of the PCC.
The other thing that I just thought of regarding your earlier question, why the delay. The fact that the decision of the ad hoc committee was being appealed while it was under appeal nothing was done with the recommended correction notice because we were investigating the appeal.
Q. Who drafted the language of the correction?

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A. I don't know specifically but this follows the guidelines of the generally accepted text that we have for this kind of situation.
Q. But you don't know who actually drafted the language?
A. No.
Q. Who typically drafts corrections that are consistent with the policy you just referenced?
A. Typically one of the staff people in our intellectual property office, we refer to the IPR office.
Q. Okay. So you think this correction was drafted by an IEEE staff member in the IPR office?
A. Yes.
Q. Do you know whether the article authors were consulted about this correction?
A. I don't know that.
Q. Do you know whether they were asked to approve the language before it was published?

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A. No.
Q. No, you don't know?
A. No, I don't know.
Q. How does this -- where does this correction appear as of today?
A. It is in our database, the IEEE Xplore digital library.
And this is our online database and we have -- for these type of items we have -- we link it to the abstract record associated with the article.
Q. Explain that last part to me that is linked to the abstract of the article.
A. Every article in our database has an index record. We call the abstract record. It is like in the old delays it would be a library index card that would point you to a particular book or something.
This is like a giant index card. It contains the bibliographic citation information to the article, name of the article, title of the article, the authors, the date and then it contains the abstract, it contains indexing keywords and then in a

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within IEEE as to whether the publisher's note similar to what IJRR published would be appropriate in this case and excluding any discussions you may have had with counsel?
A. Not excluding anything with counsel.
Q. So any conversations you are aware of would have been with counsel involved?
A. Yes.
Q. Okay. Let's move on to topic 13 of the deposition notice which relates to practices with respect to tracking downloads, sales and access to individuals and articles.
Mr. Vengraitis testified in part on this topic but you have also been designated. So some of this -- well, let me just ask you.
How as a general matter does IEEE track how many times an article is accessed or downloaded?
A. We have computer logs that we process, we keep the computer logs daily and then I think once a week we process them to

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generate statistics of how often articles are retrieved and then those statistics are rolled up to show how many articles are retrieved from each of the publications whether it be a journal or a conference that is in our database.
Q. You used the term "retrieved." Do you essentially track -- what was -- strike that.
What does "retrieved" mean in that context?
A. When a person requests to see the full text pdf that is -- I would -- that is what I am referring to, we sometimes refer to that as pdf download. I used the phrase retrieve. It is the same thing.
It is one action by the computer, by the user of the system. They push the button to say show me the pdf article and we deliver the pdf article and we count, we count that.
Q. Okay. So that would be an event that at least in the case of a nonsubscriber would trigger an obligation to pay for the

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retrieval?
A. In the case of the nonsubscribers they would have been asked to pay before we show them the pdf.
Q. Right. Okay. But you are counting that as a retrieval?
A. Yes. Well, No. No. We only count it as a retrieval if they paid the money and actually got the pdf.
Q. Okay. In the case of a subscriber who retrieves the article, you count that as retrieval as well?
A. Yes.

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REDACTED

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Q. Are you aware of any e-mails, electronic records or other documents related to the article, the thesis or IEEE's investigation that have either been destroyed or not produced to Dr. Kumar in this litigation?

A. No.

MR. STAHL: I think I am -- I have no further questions.

MR. EWING: I have no further questions either.

(Time noted: 4:02 p.m.)

ANTHONY DURNIAK

Subscribed and sworn to before me this day of 2013.

____

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Durniak

CERTIFICATE

STATE OF NEW YORK)
: Ss
COUNTY OF NEW YORK)

I, Steven Neil Cohen, a Registered Professional Reporter and Notary Public within and for the State of New York, do hereby certify: That ANTHONY DURNIAK, the witness whose deposition is herein before set forth, was duly sworn by me and that such deposition is a true record of the testimony given by such witness.

I further certify that I am not related to any of the parties to this action by blood or marriage and that I am in no way interested in the outcome of this matter.

I further certify that neither the deponent nor a party requested a review of the transcript pursuant to Federal Rule of Civil Procedure 30(e) before the deposition was completed.

In witness whereof, I have hereunto set my hand this 21st day of November 2013.

STEVEN NEIL COHEN, RPR

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Durniak

DEPOSITION ERRATA SHEET

Assignment No. 39589

Case Caption: Kumar vs. IEEE

DECLARATION UNDER PENALTY OF PERJURY

I declare under PENALTY OF PERJURY that I have read the entire transcript of my Deposition taken in the captioned matter or the same has been read to me, and the same is true and accurate, save and except for changes and/or corrections, if any, as indicated by me on the DEPOSITION ERRATA SHEET hereof, with the understanding that I offer these changes as if still under oath.

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ANTHONY DURNIAK

Subscribed and sworn to on the _______ day of __________, 2013 before me,

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Notary Public,
in and for the State of ________________.

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ANTHONY DURNIAK

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ANTHONY DURNIAK

EXHIBIT Z

EXHIBIT
PENGAD 800-631-6989
IEEE 25
11/13/11

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IEEE_000519

EXHIBIT AA

Notice of Correction

"Task Modeling and Specification for Modular Sensory Based Human-Machine Cooperative Systems"
by D. Kragic and G.D. Hager,
in the Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems, 2003, pp. 3192-3197.

After careful and considered review of the content of this paper by a duly constituted expert committee, a correction has been deemed appropriate. Specifically, references [5] and [6] cited in the paper were transposed and should be corrected as follows.

Reference [5] should be:

R. Kumar, "An Augmented Steady Hand System for Precise Micromanipulation", *Ph.D. thesis*, Department of Computer Science, The Johns Hopkins University, 2001.

Reference [6] should be:

C.S. Hundtofte, G.D. Hager, A.M. Okamura "Building a task language for segmentation and recognition of user input to cooperative manipulation systems", *10th International Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems (2002 IEEE Virtual Reality Conference)*, pp. 225-230, 2002.

EXHIBIT BB

UNITED STATES DISTRICT COURT
FOR THE DISTRICT OF MARYLAND

RAJESH KUMAR, :

Plaintiff :

vs. : CIVIL ACTION NO.:

THE INSTITUTE OF : 2:12-CV-06870-KSH-PS
ELECTRICAL AND
ELECTRONICS ENGINEERS,
INC.,
Defendant : October 15, 2013

The deposition of ANDREW DOUGLAS, taken on Tuesday, October 15, 2013, commencing at 2:34 p.m., at 3400 North Charles Street, 113 Garland Hall, Baltimore, Maryland 21218, before Shannon M. Wright, a Notary Public.

Reported by:

37cca5bd-0704-482f-a6e5-e91a17611464

A N D R E W D O U G L A S, being first duly sworn to tell the truth, the whole truth, and nothing but the truth, testified as follows:

EXAMINATION

BY MR. STAHL:

Q Good afternoon, Dean Douglas.

A Good afternoon.

Q We met a moment ago. I'm Eric Stahl. I'm here on behalf of Dr. Kumar in his copyright infringement lawsuit against IEEE.

And are you familiar with the acronym IEEE?

A Yes.

Q Okay. For the record, it's Institute for Electrical and Electronics Engineers. We'll refer to it today as IEEE.

You understand you just took an oath?

A (Nods head.)

Q And that you're obligated to answer my questions truthfully under penalty of perjury?

in any way?

MS. TURNER: I -- I object to that question --

MR. EWING: Objection to form.

MS. TURNER: -- as well. And material may be a legal term. I'm not sure what sense you're using it, but I object.

Q Can you answer the question?

A I'm having a hard time answering, so no.

Q At the bottom of the page -- closer to the bottom of the page under the heading, "Complaints to the Editor and Publisher of IJRR," the last sentence of that states, Alleged violations of copyright are beyond the scope of institutional review.

So is it fair to say that you're not saying one way or the other whether the articles that Dr. Hager coauthored infringed Dr. Kumar's thesis as a matter of law?

A Correct.

CERTIFICATE OF DEPONENT

I hereby certify that I have read and examined the foregoing transcript, and the same is a true and accurate record of the testimony given by me.

Any additions or corrections that I feel are necessary, I will attach on a separate sheet of paper to the original transcript.

____

ANDREW DOUGLAS

STATE OF MARYLAND SS:

I, Shannon M. Wright, a Notary Public of the State of Maryland, do hereby certify that the within named, personally appeared before me at the time and place herein set out, and after having been duly sworn by me, was interrogated by counsel.

I further certify that the examination was recorded stenographically by me and this transcript is a true record of the proceedings.

I further certify that the stipulations contained herein were entered into by counsel in my presence.

I further certify that I am not of counsel to any of the parties nor an employee of counsel nor related to any of the parties nor in anyway interested in the outcome of this action.

As witness my hand and notarial seal this 28th day of October 2013.

My commission expires
July 26, 2015 ---------------------

Shannon M. Wright

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EXHIBIT CC

JOHNS HOPKINS
UNIVERSITY

Whiting School of Engineering
Wyman Park Building 4th Floor
3400 N. Charles Street
Baltimore MD 21218-2681
410-516-6771 / douglas@jhu.edu

Andrew S. Douglas
Vice Dean for Faculty

Dr. Nicholas Jones, Dean
Whiting School of Engineering
Johns Hopkins University

February 28th, 2012

Dear Nick

Associate Research Professor Rajesh Kumar has questioned the conduct of Professor Greg Hager and his co-authors regarding two technical publications. The first was published in the International Journal of Robotics Research (IJRR) (Kragic, Marayong, Li, Okamura and Hager, 2005) while the second was published in the Proceedings of IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS) (Kragic and Hager, 2003).

I have completed an inquiry into the allegations made by Dr. Kumar against Dr. Hager and his coauthors and others.

Allegations

Dr. Kumar is imprecise in his allegations, but in a letter dated January 18th 2012, Dr. Kumar outlined three areas of concern. Dr. Kumar states that "I am looking to your experience and judgment to determine if this is really the case, and if these elevate to the level of misconduct." At the same time Dr. Kumar has contacted Dr. John Hollerbach (editor of the IJRR) and Sage (the published of IJRR) making similar allegations.

In each case, I examined the allegation as a potential breach of either research misconduct or of professional misconduct.

The first allegation concerns the IROS and IJRR articles by Kragic et al. In his January 18th letter, Dr. Kumar compares Figure 5.13 (page 70) of his PhD thesis to Figure 1 in the IROS article, and to Figure 5 in the IJRR article and asks the question "Would you consider these as

independent[?]". On the other hand, in a February 3rd 2012 e-mail to IJRR, Dr. Kumar alleges that "The IJRR article is a derivative work in every respect."

The second allegation relates to a press release issued by Johns Hopkins in August, 2011 titled "A Robot that Helps Teach the Language of Surgery." Dr. Kumar states that "This press release was issued without my knowledge ...". The article was published by the Institute for Basic Biomedical Sciences (in the SoM) and was written by Melissa Hendricks. The article references Dr. Rene Vidal ("who leads the machine-learning aspects of the project"), Dr. Nicolas Padoy, (who demonstrated the da Vinci robot) and Dr. Grace Chen (a Johns Hopkins gynecological surgeon and the surgeon advisor on the team).

The third issue relates to an article in the Journal of Laparoendoscopic & Advanced Surgical Techniques (JLAST 2006) by Hanly et al. and "related conference abstracts." Dr. Kumar is the third listed author and the corresponding author is Professor Michael Marohn in the SoM. Dr. Kumar claims that what "follows should have been credited differently, included additional authors, and should have been published only after all authors had provided appropriate input." In a later communication, Dr. Kumar identifies Professor Steve Butner as someone who "contributed significantly to the work, was an investigator on the grant, and worked hands-on to develop the system. He may have additional documentation to support his role." No further information is provided by Dr. Kumar.

Basic Background

Dr. Kumar was a PhD student of Dr. Russell Taylor in the CISST ERC prior to the arrival of Dr. Greg Hager in 1999. Since Dr. Kumar's thesis involved early developments in the algorithms and architectures for cooperative micro-manipulation with the Steady Hand Robot (SHR), Dr. Taylor suggested that, then doctoral candidate, Kumar consult with Hager on his thesis work. One example in Kumar's thesis was the application to retinal microsurgery using the SHR.

Kumar submitted his doctoral thesis in March of 2001 and then left the Whiting School for a position at Foster Miller (a military robotics manufacturer). Kumar and Hager continued to have active collaboration, including joint work on an SBIR project. This work involved computer vision and was unrelated to the topic of Kumar's doctoral thesis.

Kumar then worked for Intuitive Surgical (manufacturer of the da Vinci system we have in the LCSR) and continued his collaborations with Dr. Hager.

Dr. Danica Kragic arrived at the CISST in 2003 for a short-term post doctoral position (February through April 2003). According to Dr. Hager, Kragic "became interested in the development of human-machine collaborative systems" and Kragic "developed her own software framework for human-machine task specification, and I [Hager], in parallel, developed a general framework for 'virtual fixture' augmentation." The IROS 2003 paper is the result of this work and it uses SHR retinal microsurgery as an example. This paper cites Kumar's thesis, an ICRA conference paper for which he was the first author, and an International Journal of Robotics Research (IJRR) paper on the steady hand robot on which he was a co-author.

Dr. Kragic then led a project to consolidate independent research by Dr. Allison Okamura's group on other aspects of human-machine collaboration with the work being done by Hager. As

a result, a single paper, first presented at the International Symposium of Robotics Research (ISRR) in 2003, appeared, by invitation in IJRR (2005).

Dr. Kumar returned to the Whiting School in October 2007 as an Assistant Research Professor with support from grants awarded to Hager and Taylor. Consistent with his position, Kumar did secure some independent funding for his research. Effective March of 2011, Kumar was promoted to Associate Research Professor. In early September of 2011, Kumar ceased collaborations with Hager.

Timeliness

The IROS 2003, IJRR 2005 and JLAST 2006 papers are now at least 8, 6 and 5 years old. Both the NSF and DHHS Office of Research Integrity consider three years as the required time to preserve data. The IROS 2003 and IJRR 2005 were in Dr. Kumar's field and he should have known of their existence prior to 2012. Dr. Kumar was a co-author on the JLAST 2006 paper and should have addressed authorship issues prior to publication.

Response to Allegation One

Information provided by Hager

The IROS 2003 paper does reference Dr. Kumar's work. Indeed, the second paragraph of section 2 states that "The work pursed in this paper builds upon the research presented in [5] and [6]." Reference 6 is Dr. Kumar's thesis, and references 4 and 14 also reference Dr. Kumar's papers. The IROS paper is different from Dr. Kumar's thesis as it, according to Professor Hager, "describes a new, more general, system design, a new, more general, mathematical way of describing virtual fixtures, and a new, more general, specification language based on xml."

Regarding the IJRR 2005 paper, Professor Hager provides the following general background; "The work described in both Dr. Kumar's thesis and our papers was performed at JHU in the Center for Computer-Integrated Surgical Systems and Technology, an NSF-funded Engineering Research Center. One of the experimental test-beds in that laboratory was the JHU Steady Hand Robot (SHR), developed for, and primarily applied to, microsurgery. This research began in the late 90's and continues to this day at JHU using similar focusing applications and subsequent generations of the hardware and software."

To address the allegation regarding the "independence" or "derivative nature" of Figure 1, Professor Hager notes that their Figure 1 "is simply a descriptive figure showing how Dr. Kragic implemented her system. It is a graphical rendition illustrating the output of the GUI shown in Figure 4 and rendered in XML in Section VIII. It is similar to Dr. Kumar's thesis figure since, as we have explained above (and Dr. Kumar also admits), Dr. Kragic was working in the same lab, on the same hardware, on the same motivating problem roughly two years later."

Inquiry Assessment

The citations provided in IROS 2003 are appropriate.

Kumar's work is not cited by the IJRR 2005 paper. While Kumar's work could have been cited, my assessment is that it was not necessary to cite it. In any event, the reviewers of IJRR did not think citation to Kumar's work was necessary.

My independent assessment is that the figures by Kragic, while similar in look to Figure 5.13 in Kumar's thesis, are fundamentally different because the logic sequences are different. This is consistent with Hager's explanation that "The figure differs because it was a different implementation and solution of the problem."

Response to Allegation Two

This allegation relates to a press release, published by the School of Medicine, which describes, in layman's terms, the "language of surgery." The article is no longer available online. It is difficult to understand why Dr. Kumar feels he should have been consulted about the article. Appropriate sources are used and there is no possibility for either research or professional misconduct on the part of any Whiting School faculty member.

Response to Allegation Three

This third issue relates to an article in the Journal of Laparoendoscopic & Advanced Surgical Techniques (JLAST 2006) by Hanly et al. for which Dr. Kumar is the third listed author and the corresponding author is Professor Michael Marohn in the SoM. Since Dr. Kumar is listed as an author, there is no authorship dispute as far as Dr. Kumar is concerned.

However, Dr. Kumar claims that what "follows should have been credited differently, included additional authors, and should have been published only after all authors had provided appropriate input". The allegation is unsubstantiated, applies to persons other than Dr. Kumar and comes well after reliable records could be used to substantiate appropriate authorship. In any event, this allegation should have resolved the issue prior to publication.

Complaints to the Editor and publisher of IJRR

Dr. Kumar has complained to both the editor of IJRR, Dr. Johns Hollerbach and to the publisher of the IJRR, Sage. These complaints include the allegation of "violation of copyright."

I have considered the allegations regarding authorship and attribution that are appropriately raised at the institution. Alleged violations of copyright are beyond the scope of institutional review.

Findings

These allegations did not allege violations meeting the definition of research misconduct under the School's Procedures for Dealing with Issues of Research Misconduct.

This inquiry found no evidence of professional misconduct warranting further investigation.

Whether or not Dr. Kumar's thesis and papers should be cited by those of Kragic et al. IJRR 2005 is a matter for the IJRR and its reviewers and is not an issue of misconduct.

Suggested Action Items

1. Inform Dr. Kumar that this inquiry is complete and that no evidence of any misconduct has been found.
2. Inform Dr. Hager that this inquiry is complete and no evidence of any misconduct has been found
3. Inform Dr. Hollerbach of IJRR that we have completed out inquiry and that no evidence of any misconduct was found.

Please let me know if you have any questions.

Sincerely